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MULTIMODE PHASED ARRAY TUBE

EIMAC Division of Varian

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ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This contract was for the test and evaluation of the tetrode type 8590/4CPX250K for long pulse and high duty factor service in phased array applications. The limits of the tube were determined. Also, a new tetrode with the same size and outline of the 8590 was developed to provide pulse lengths to 10ms with a duty factor to 0.03. The new tetrode uses a CPC (coated powder cathode) and a new anode cooler design to permit an anode dissipation of 500 watts. An rf cavity to work with the new tetrode was developed to operate at 435 MHz with 10kw

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output power. A bandwidth of 30 MHz to the -1dB points was attained using overcoupled circuits. The power gain of the tube and cavity combination was over 10dB.

EVALUATION

The objectives of this program were to determine the long pulse characteristics of the 8590/4CPX250K power tetrode and establish its limitations in regard to duty factor. It was also an objective to develop a new tetrode with the same size and outline which would be capable of operation at up to 10 milliseconds and a duty factor of 0.03.

The new tetrode developed under this effort was given a X2179F number. This tube has a Coated Power Cathode (CPC), a newly designed cooler to provide an anode dissipation of 500 watts and was tested at peak power of up to 10.23 KW. The tube can be operated over 30 MHz bandwidth in a cavity designed and built during this program and provided a 10 dB power gain in this cavity.

The tetrode designed in this program is currently undergoing life test and evaluation at the contractor's plant and five tubes are to be similarly tested at RADC (in-house).

These tubes could have application in long pulse phased array applications and could also be used in UHF communications applications. It is also conceivable that current Air Force equipments could be retrofitted using this tube to increase the average power capability of these systems.

Anthony S. Cardello

ANTHONY S. CARDELLO
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SUMMARY

The Multimode Phased Array Tube Program, under contract number F30602-74-C-0158 performed for the Rome Air Development Center, had three main requirements.

The first requirement was to perform tests on an existing tetrode tube currently in service in a phased array installation. The tetrode type is the 8590/4CPX250K. The tests to be performed were to determine the limit of the 8590 in long pulse length and high duty factor service. As a minimum requirement the 8590 was to be tested using pulse lengths of at least one millisecond, a duty factor of 0.06 and a peak power output of up to 10kw

The second requirement was to design a tetrode with new cathode material and better cooling capabilities which would have the same size and outline as the type 8590.

The new tetrode was to have, as a goal, the capability of pulse lengths up to 20 milliseconds and a duty factor up to 0.06. The duty factor of 0.06 was for a series of half sine wave 30 nanosecond pulses during the 20 millisecond pulse.

The third requirement was to design and deliver an rf cavity amplifier which would use the new tetrode. The cavity and tube combination was to deliver 10kw power output at a frequency of 435 MHz with a bandwidth of 30 MHz. The thermal management of the amplifier was to be such that the long pulse lengths and high duty factors could be attained.

The limits of the 8590 as presently manufactured were determined. Three experimental versions were designed, manufactured and tested in the rf cavity amplifier under the conditions specified in the contract Statement of Work. During the final acceptance test the X2179F version of the new tetrode delivered 10.23kw output power with a 10 millisecond square wave pulse at a duty factor of 0.03. This duty factor is approximately the same as 0.06 for the series of half sine wave pulses during the 10ms pulse. The pulse recurrence rate was three pulses per second. The rf amplifier stage power gain was greater than 10dB.

Five tubes have been retained to conduct additional life tests at the vendors expense. Five tubes have been sent to the Rome Air Development Center.

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1.0 INTRODUCTION

This is the final report on the Multimode Phased Array Tube Program, a study and investigation of a tetrode tube for providing broadband, long pulse, high power and high duty factor service in operational phased arrays. Present day and future requirements of system designers indicate a need for such a tube. This research has been conducted by the EIMAC Division of VARIAN, San Carlos, California for the Rome Air Development Center, Griffiss Air Force Base, New York, under Contract Number F30602-74-C-0158.

The contract requirement was to perform tests and evaluation of the type 8590 (EIMAC type 4CPX250K) power tetrode at pulse widths of at least one millisecond, 0.06 duty and a peak power of up to and including 10 kilowatts. As a part of this evaluation, the anode cooling problem associated with the long pulse and high duty operation was to be investigated.

Based upon the results of the type 8590 tests and evaluation, a new UHF ceramic power tetrode was to be designed, developed and fabricated to meet the following characteristics.

Center frequency	435	MHz
Electronic bandwidth	±15	MHz
Peak power output	10	kw objective
Pulse width	10 20	millisecond minimum millisecond objective
Maximum duty cycle	0.06	
Pulse Repetition Rate	3	pulse per second
Gain	10	dB minimum
Efficiency	45	% minimum
Cooling		Forced Air
Maximum pulse droop		Less than 0.2 dB
Minimum design life	10,000	hours
Outline and size		Similar to the EIMAC type 4CPX250K. Preferably identical.
Minimum pulse width for full duty	100	microseconds

As an additional requirement of this contract, one radio frequency cavity was to be designed, fabricated and delivered. The cavity was to be tailored to fit the deliverable tube and

designed to enable the tube to deliver full rated power at the frequency of interest and compatible with the duty factor specified.

The technical effort and tests are discussed in Section 2. Conclusions and recommendations are discussed respectively in Sections 3 and 4.

2.0 TECHNICAL DISCUSSION

Evaluation of tubes during this program has progressed along two parallel paths. In one the tubes have been tested using long video pulses only, in a grid-pulsed modulator circuit. In the second, rf evaluation was done in an amplifier chain, using grid pulsing, with the TUT (Tube-under-test) last in the chain.

The video long pulse testing started in the second month of the contract. The pulse evaluation equipment was on hand and required only some modification to accommodate the long pulses in order to commence testing. A considerable amount of test time has been accumulated (11,846 tube hours). Some down time occurred due to an occasional equipment failure or due to time needed to measure the static characteristics of a tube being life tested.

At the start of this program the rf testing was to be done by using the 8590/4CPX250K evaluation and test equipment in existence in the EIMAC manufacturing plant. It became evident that interference from the tube manufacturing schedules would allow very little time for long pulse testing in this equipment. It was necessary to put considerable additional effort into assembling a driver chain, pulse modulator and crowbar. Therefore less actual rf testing time was available than had been anticipated.

EXPERIMENTAL TUBE CONSTRUCTION

X2179E Dispenser Cathode Tetrodes

The dispenser cathode consists of a porous tungsten substrate, impregnated with Barium and Calcium Aluminates. The cathodes used in this work had a molar ratio of 4 Ba: 1 Ca: 1 A in a tungsten matrix; the cathode manufacturer's type designation was S84-411.

The dispenser cathode is very resistant to gas poisoning and arcing, and has furnished long life at high average current density and, for these reasons, was evaluated in experimental vehicles similar to the type 8590 (with the type designation X2179E).

Four X2179E tetrodes were assembled and processed. These tubes had the same electrode dimensions and cathode area (2 square centimeters) as the 8590 and could be evaluated in the rf cavity without cavity modifications.

Three tubes were operated with a pulse rf signal, as

discussed in the section on RF tests. These tubes, however, could not be tested at the desired 10kw power output because:

1. The peak space-charge-limited electron emission capability of the cathodes was low at normal operating temperatures (9 amperes at 1100 degrees centigrade). Fifteen amperes is required for the full 10kw output power.

2. When the cathode temperature was increased to 1150+ degrees centigrade in order to obtain higher emission, evaporation products, especially barium, from the cathode contaminated the grids and resulted in high grid emission and prevented operation at high voltage.

At this point work on dispenser cathodes was discontinued in favor of the coated-particle-cathodes described in a following section.

X2179F With Improved Anode Cooler

The results of a study of the anode cooling problem associated with high power, high duty operation of the type 8590 were incorporated in the design of an improved anode cooler for the type 8590. The experimental type designation was the X2179F. The X2179F had the standard (for the type 8590) triple-carbonate oxide cathode. The only deviation from the 8590 design was in the anode core and cooling fin assembly. Details of the design change are presented in the section on Anode Cooling; briefly, they consisted of a thicker anode wall and a new rippled-fin design to replace the louvered fins of the 8590.

Twenty-eight type X2179F tetrodes were manufactured. These were used for the anode cooling tests and were evaluated in a high duty, long pulse rf amplifier cavity. The anode cooling tests demonstrated much improved performance at high anode dissipation and resulted in an increase of the maximum anode dissipation rating from 250 watts for the 8590 to 500 watts for the X2179F and the X2179G. (The X2179G, discussed next, incorporated the same anode cooler design).

RF tests of an X2179F were conducted at the contract objective power and duty levels; 10kw peak power output at 10 millisecond pulse duration and 3 pulses per second, also at 10kw with 0.25 milliseconds pulse length and 0.06 duty factor.

X2179G Tetrode with CPC

The X2179G tetrodes utilized the CPC (coated powder cathode a development of Maurer and Pleass* of Bell Telephone Laboratories. The CPC material was similar to the material used in

a cathode evaluation program conducted by EIMAC for General Technologies Corporation. (Subcontract 1 of USAECOM Prime Contract No.DAAB05-77-C-2607, 1970 to 1972). It consists of a triple carbonate Ba, Sr, Ca (Ca 0_3) powder, each particle of powder being coated with nickel to the extent of 2 wt percent.

The nickel coating increases the electrical conductivity of the coating and reduces sublimation of barium from the converted oxide cathode surface. The peak emission capability of the cathode is comparable to the conventional oxide cathode. In the aforementioned evaluation program, diodes were life tested for 1000 to 2500 hours at 0.8 amperes per square centimeter, dc, without significant degradation and additional studies indicated that sublimation rates were substantially lower than uncoated oxide cathode material.

The X2179G tetrode design incorporated three major changes (compared to the 8590). These were:

1. CPC material was substituted for the triple carbonate powder in the cathode spray mix.

2. Heater was redesigned for 30 percent higher current at the operating voltage of 6 volts.

3. An improved anode and cooling fin assembly was used, as discussed in the Anode Cooling Section. This was identical to the X2179F cooler, with the same cooling characteristics.

The change of heater (2 above) was required because the thermal emissivity of the coated powder cathode is higher than the conventional oxide coating and more power is lost by radiation at the same operating temperature.

The assembly, processing, and pumping methods and schedules for the type 8590 were used, unchanged, for the X2179G tubes. Twenty X2179G tetrodes were built and processed in one lot. These tubes were given all of the part 1, part 2, and part 3 tests of the Military Specification MIL-E-1/1670A(USAF) for the type 8590 tube (except life tests) and were in complete conformance with the specification limits except for heater current (If).

*D.W. Maurer and C.M. Pleass,"The CPC: A Medium Current Density, High Reliability Cathode", Bell System Technical Journal, December, 1967, pp 2375-2404.

The test results on these tubes were used to develop the proposed limits for the provisional tube specification sheet in the Appendix.

X2179G Full Specification Tubes

Five of the X2179G tubes from the production lot of 20 tubes have been fully tested according to Part 1 (Production) and Part 2 (Design) of the Provisional Specification, including the power gain test. Prior to performing the latter test, they were aged in the rf cavity, using the aging schedule described in a following section. These tubes will be submitted to the Air Force, RADC, as the "Full Specification Tubes". Five additional tubes are being aged and prepared for the proposed life testing program at EIMAC in the rf cavity under pulsed operating conditions.

The test results for the five "Full Specification" tubes are shown in Table 1(A) and (B). The test conditions were those conditions listed in the Provisional Tube Specification in the Appendix. All of the tubes had characteristics well within the limits of the specification, indicating good quality and uniformity within the lot.

ANODE COOLING

A significant aspect of the long pulse, high duty factor mode of operation is the high value of the anode dissipation and its effect on the operating temperature of the envelope of the tube, particularly the brazed seal surfaces. Under the maximum operating conditions in an rf grid-pulsed amplifier, 10kw output at 0.06 duty, the average anode dissipation is 400 to 500 watts, with a peak dissipation of 6700 to 8300 watts. The latter figure represents a peak power density on the inside surface of the copper anode of 2 kilowatts per square centimeter, a moderate value for copper, and no problems of high transient temperature rise and stress corrosion cracking of the copper are expected to appear. This assumption was confirmed by examination of the anodes of tubes tested in the video test program at peak anode dissipation up to 12.5 kilowatts.

However, the 4CPX250K/8590 tetrode is rated for 250 watts anode dissipation and it requires a prohibitively high flow of cooling air, with a large static head, to cool the tube adequately at 500 watts dissipation.

The 4CPX250K/8590 is shown in section through the cylindrical axis in Figure 1. The anode is a thin-walled copper cylinder with a set of folded louvered fin stock brazed between the anode and an outer jacket which is a copper cylinder

TABLE 1(A) TEST RESULTS FOR THE X2179G FULL SPECIFICATION TUBES TESTED PER PROVISIONAL TEST SPECIFICATION

Test	Electrode Voltage	Electrode Current	Total Grid Current	Pri. Grid Emission Control	Emission Screen	Heater Current
Symbol	Ec1	Ic1	-Ic1	-Isg1	-Isg2	If
Unit	Vdc	mAdc	µAdc	µAdc	µAdc	Aac
Limits:						
Min.	35.0	-7.0	---	---	---	3.1
Max.	48.0	+3.0	15	25	250	3.6
Serial No:						
A6FK-4540	39.1	-2.4	1.0	0.9	1.1	3.48
A6FK-4541	40.5	-2.5	1.0	0.9	1.1	3.42
A6FK-4542	41.1	-2.6	1.0	0.8	1.1	3.44
A6FK-4543	39.2	-2.6	1.0	0.8	1.1	3.46
A6FK-4544	40.8	-3.1	1.0	0.8	1.1	3.44

TABLE 1(B) TEST RESULTS FOR THE X2179G FULL SPECIFICATION TUBES TESTED PER PROVISIONAL TEST SPECIFICATION

Test	Current Division			Direct Interelectrode Capacitance (Gr. Grid)			Power Gain
Symbol	egk	ic1	ic2	Cin	Cout	Cpk	po
Unit	v	ma	ma	pF	pF	pF	kw
Limits:							
Min.	5.0	---	---	13.0	3.90	---	10.0
Max.	16.0	200	260	16.5	4.35	0.01	----
Serial No:							
A6FK-4540	10.3	75	120	15.3	4.14	0.006	10.0
A6FK-4541	10.2	72	125	15.2	4.13	0.006	10.0
A6FK-4542	10.2	75	125	15.2	4.11	0.006	10.0
A6FK-4543	11.5	90	125	15.3	4.08	0.007	10.0
A6FK-4544	10.5	82	132	15.0	4.11	0.007	10.0

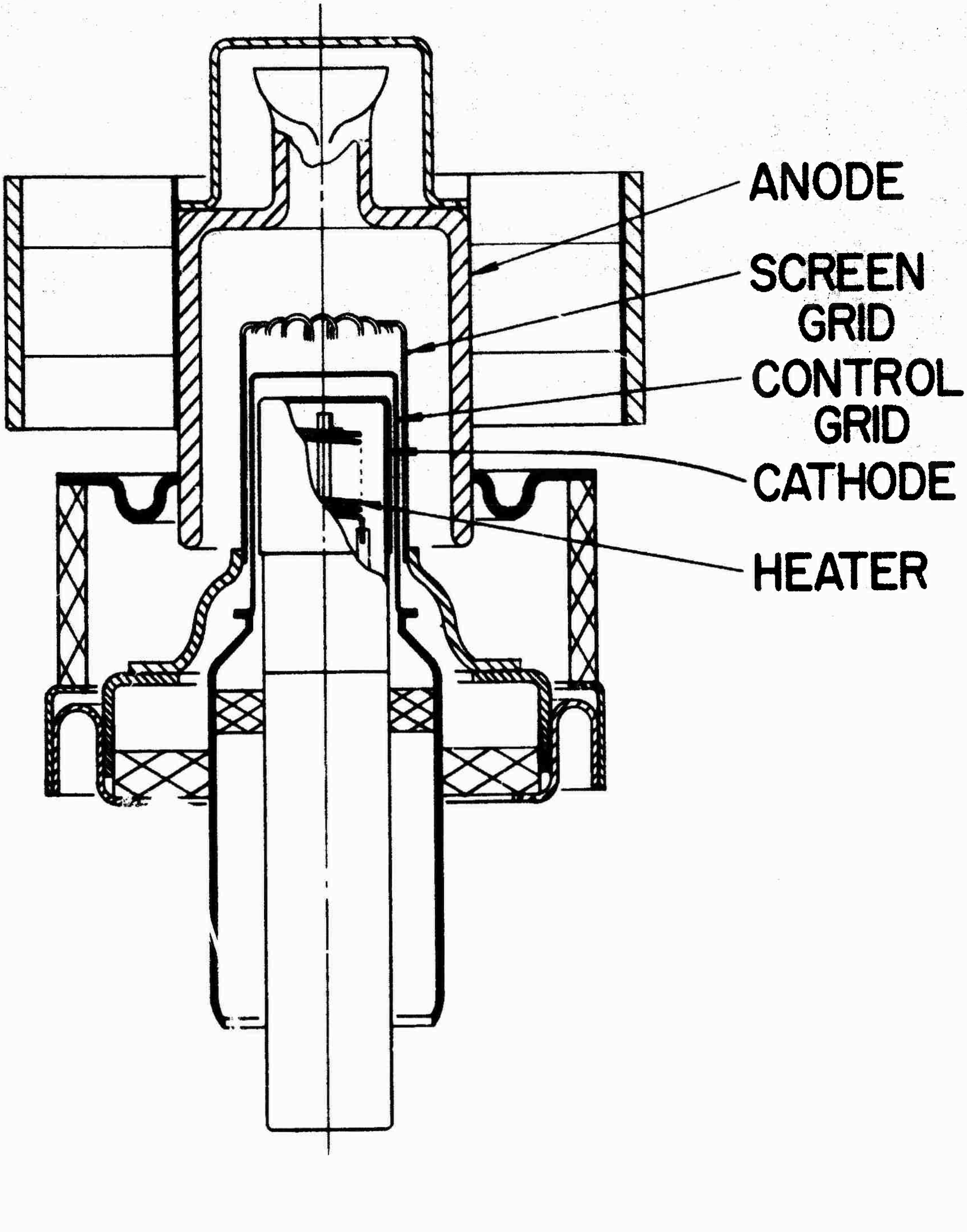


FIGURE 1. Section through Axis - 4CPX250K

similar in thickness to the anode. The louvered stock for fins is shown in Figure 2, and the anode, fins, and jacket are shown in Figure 3.

An analysis of the anode and anode cooler design of the 4CPX250K showed that the major problem was low thermal conductivity of the anode core and the louvered cooling fins in the axial direction, from the point of impingement of the electron beam on the inside of the anode to the fin-to-air heat exchange surface.

The cooling fins are louvered by shearing through the fin between the fold lines and offsetting the resulting segments as shown in Figure 4. This configuration increases turbulence of the air flowing through the fins but prevents any heat flow across the sheared edges.

The anode cooler assembly was redesigned, using a new type of folded fin stock, also shown in Figure 2. The fins are "rippled" along the fold lines to increase turbulence but are continuous without sheared sections. The depth of the folds is less than in the 8590 fins, allowing the anode wall thickness to be doubled without increasing the jacket diameter.

Figure 4 shows the axial section of the experimental tubes (X2179F and X2179G) made with the new anode design. This section shows the increased (relative to 8590) wall thickness of the anode outside the envelope proper, and the long, unbroken fins. Beside increasing the anode wall thickness, the fins were lengthened and the opening between the anode-screen insulator and the cooling fins was increased by 40 percent in order to decrease the pressure drop at the entrance of the cooling fin section. Table 2 below lists comparative characteristics for the 8590 cooler design and the improved cooler.

TABLE 2. AIR COOLER DIMENSIONS

Dimension		Type	
	Unit	8590	X2179F/G
Anode wall thickness	cm	0.16	0.31
Fin length, axial	cm	1.55	1.90
Fin depth, radial	cm	1.00	0.83
Fin surface area	cm^2	188	188
Air Velocity (15 CFM)	m/s	9.9	10.7
Number of fins (folds)	-	60	60
Entrance area, seal-to-fin	cm^2	3.0	4.2

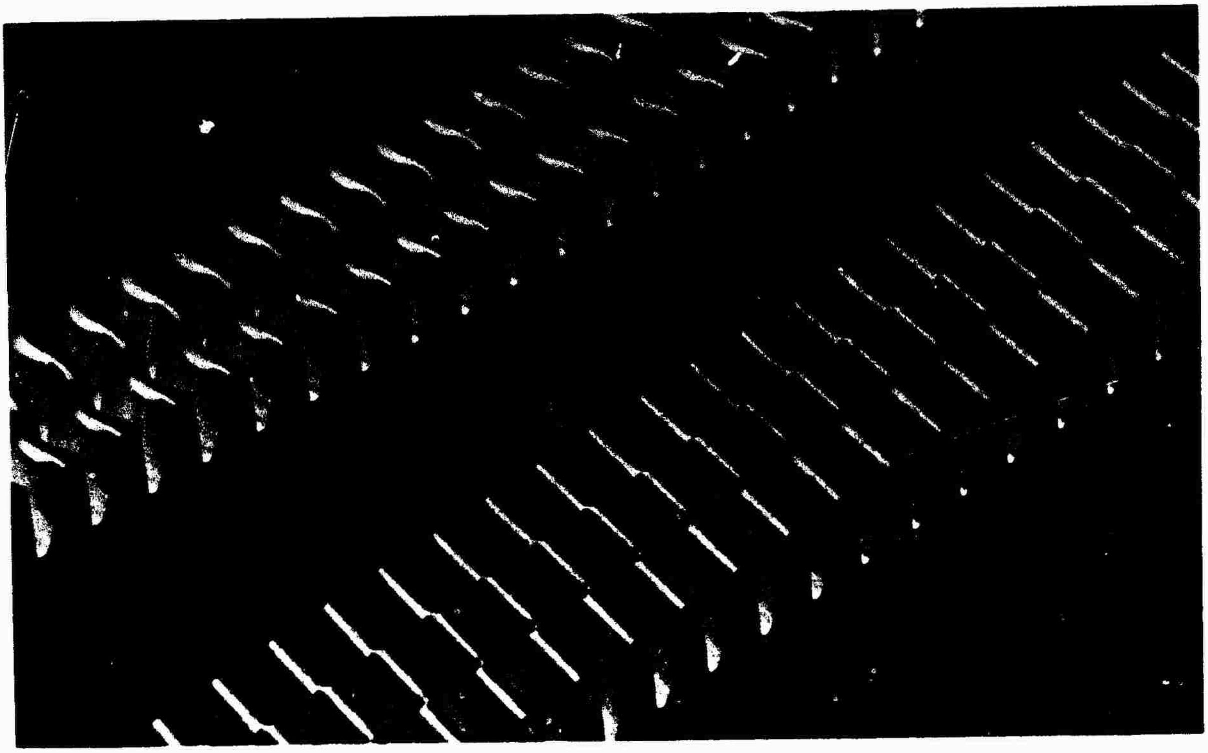


FIGURE 2. Above left, "ripple" anode cooling fin stock for X2179G; below right, louvered fin stock for 8590 Tetrode.

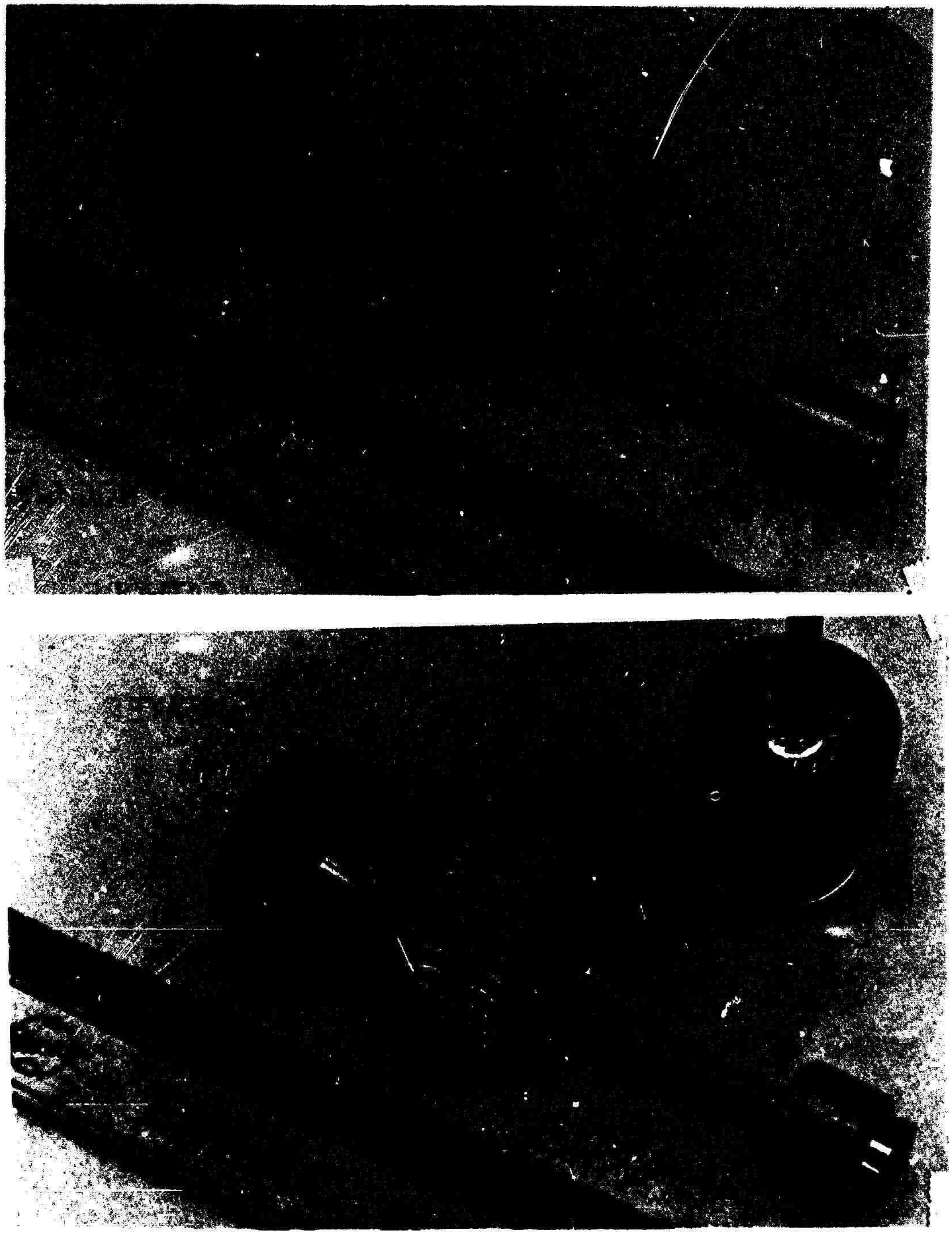


FIGURE 3. (Upper) 8590 Anode cooler parts.
(Lower) X2179F/X2179G Anode cooler parts and Anode Assembly

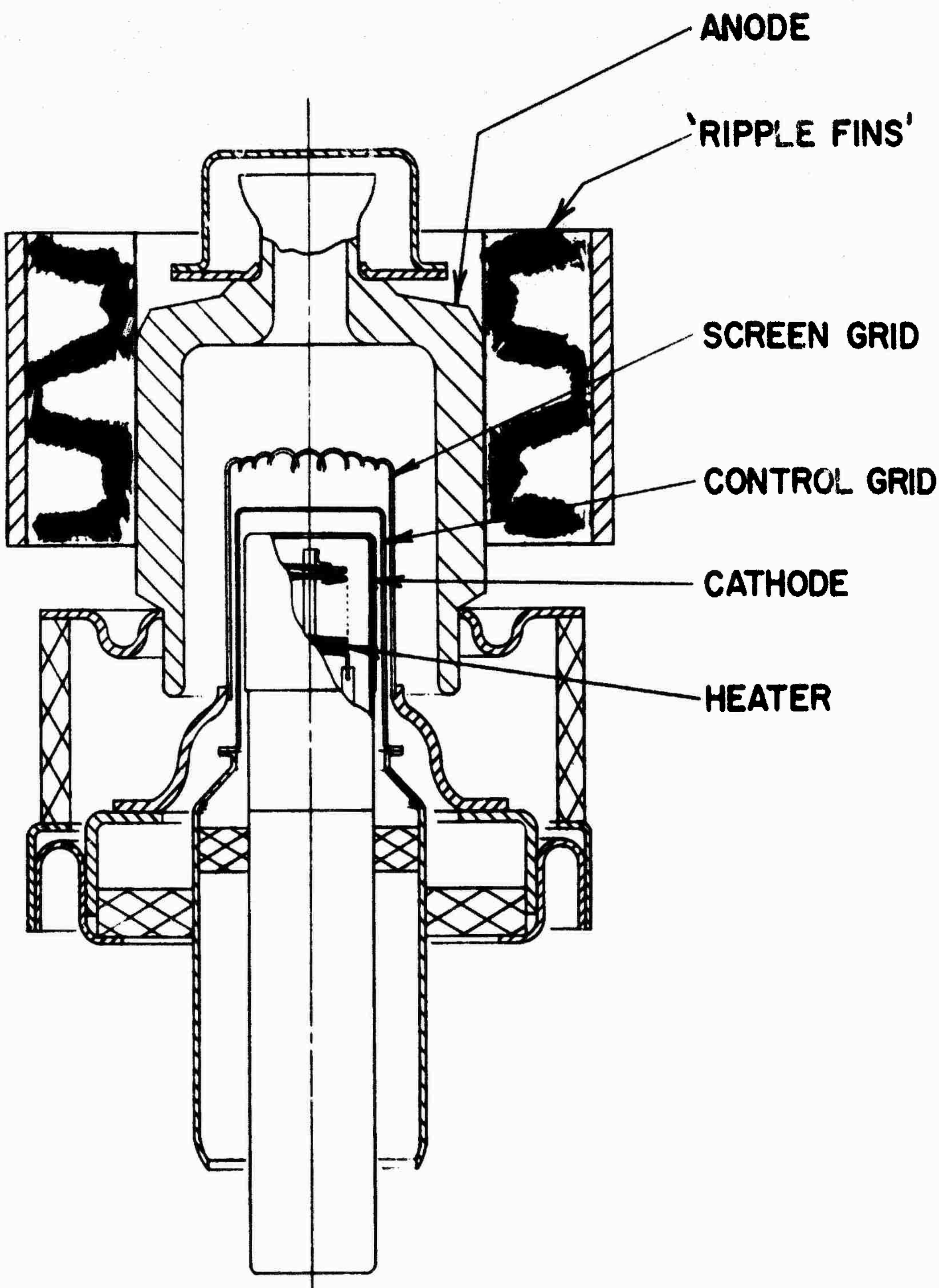


FIGURE 4. Section through Axis - X2179G

ANODE COOLING TESTS

Two type X2179F tubes, which were basically type 8590/ 4CPX250K tetrodes, except for improved anode design, were tested to determine the performance of the anode cooler. The anode design was identical to the X2179G tetrodes with coated particle cathodes. Two type 8590 tubes were tested under the same conditions to provide a comparison.

The test setup is schematically shown in Figure 5. The tube was suspended by its anode in the top plate of a cylindrical plenum without a socket. Electrical connections were made by soldering wires directly to contact area. Thermocouples were peened into holes in the anode core.

During the tests, readings of anode core temperature, plenum air temperature, and pressure difference between plenum and atmospheric pressures were recorded at specific air flow rates within the range 2.6 cfm to 17.5 cfm for anode dissipation levels of 250 watts, 400 watts, and 500 watts. These test conditions were duplicated for each tube so that minor errors in flow rate metering would not affect comparison of results.

Test Results

The data are presented in a reduced form in Figure 6, (type 8590) and Figure 7, (X2179F). These figures show the static pressure head, Δp, across the cooler in inches of water gage and the "heat transfer" coefficient ($P_p/\Delta T$) for the anode as functions of the airflow in cubic feet per minute.

The pressure head, ΔP, is simply the plenum manometer reading. The measurements were taken at sea level, with very nearly standard conditions of atmospheric pressure and temperature. The coefficient $P_p/\Delta T$ is the anode dissipation in watts, divided by the difference between the temperature of the anode core (hottest point on the anode) and the incoming air temperature.

These data were used to determine minimum anode cooler airflow requirements for the 8590 and the X2179F under the following conditions:

Maximum anode temperature	225°C
Air temperature	35°C
Altitude	Sea level (760mm Hg)

The air flow requirements of the old and the new cooler design, computed for the above conditions, are compared in the table below.

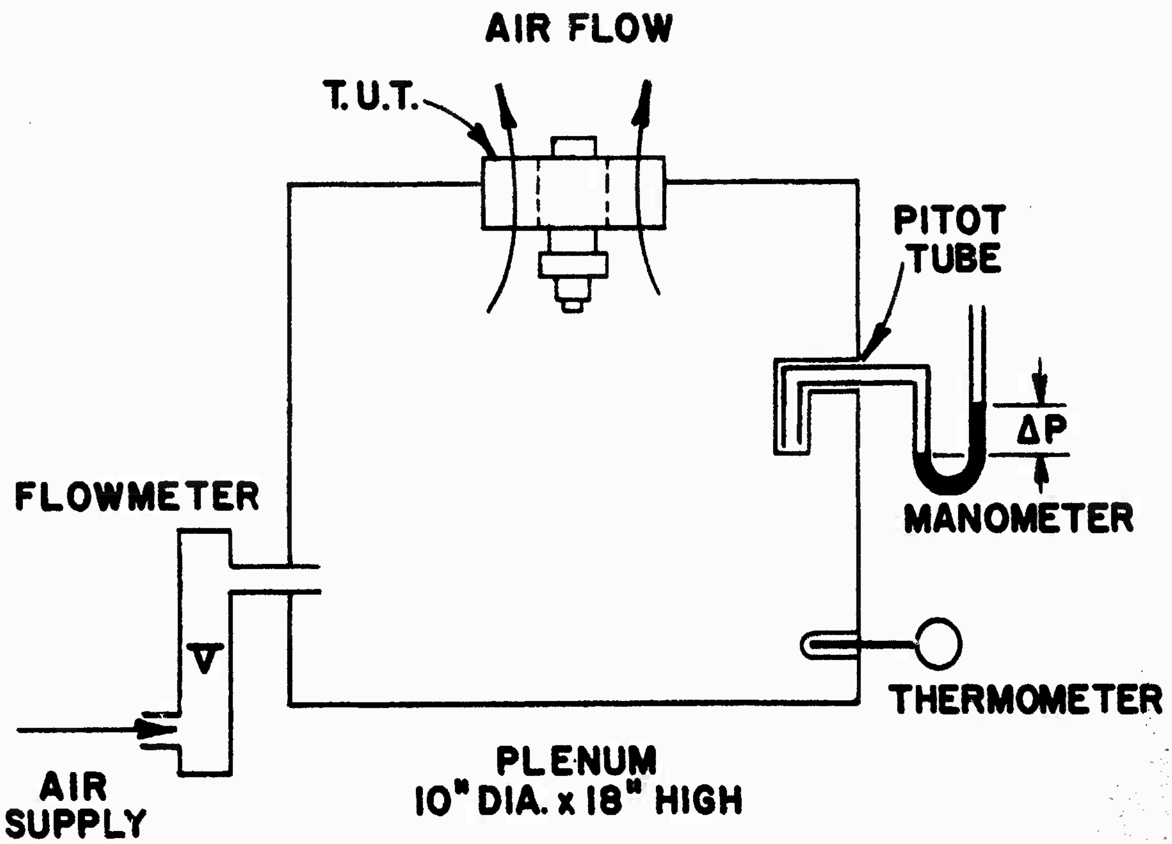


FIGURE 5. Air Cooling Test Setup
X2179F and 8590

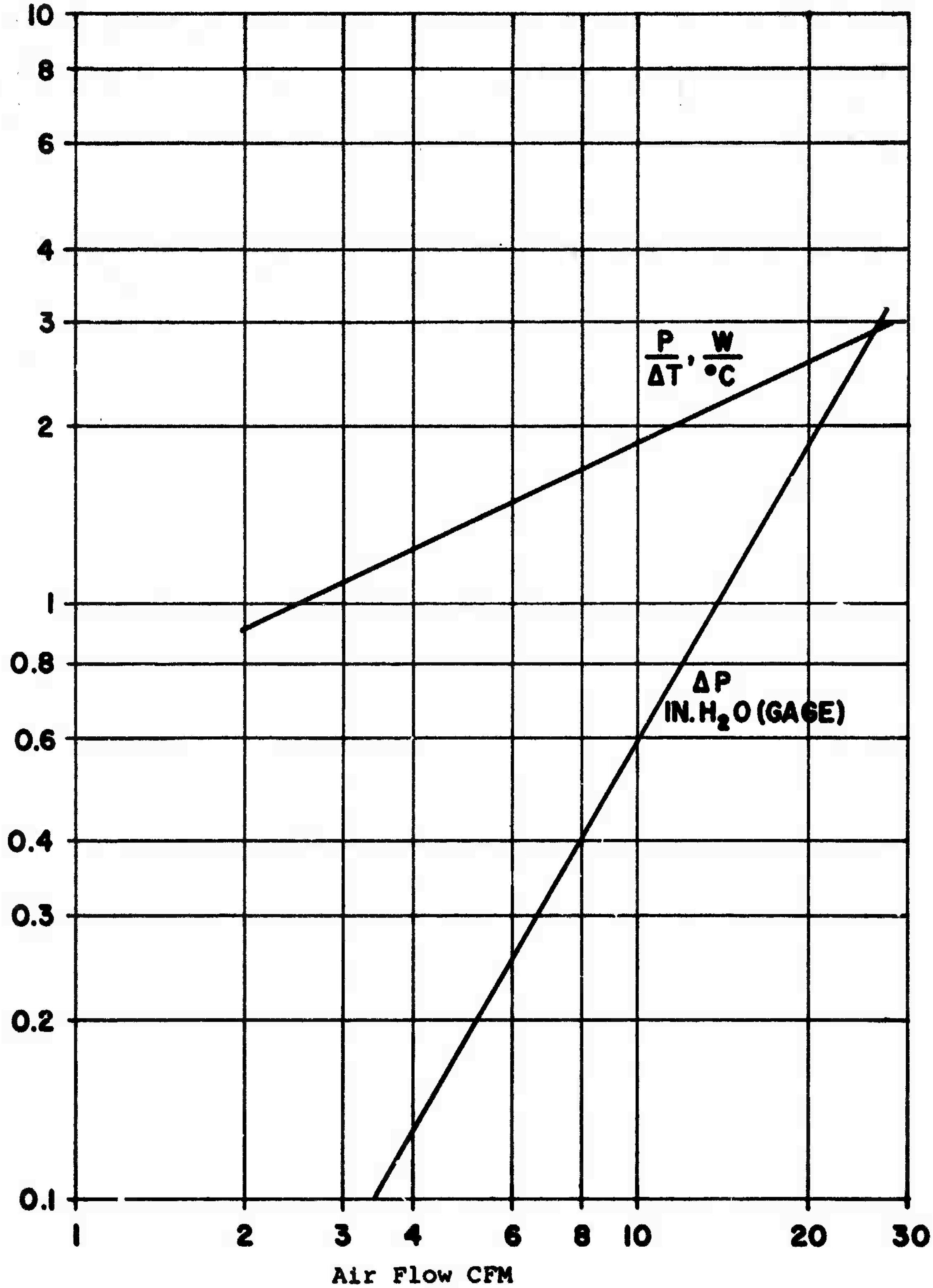


FIGURE 6. Anode Cooling Characteristics of the Type 8590

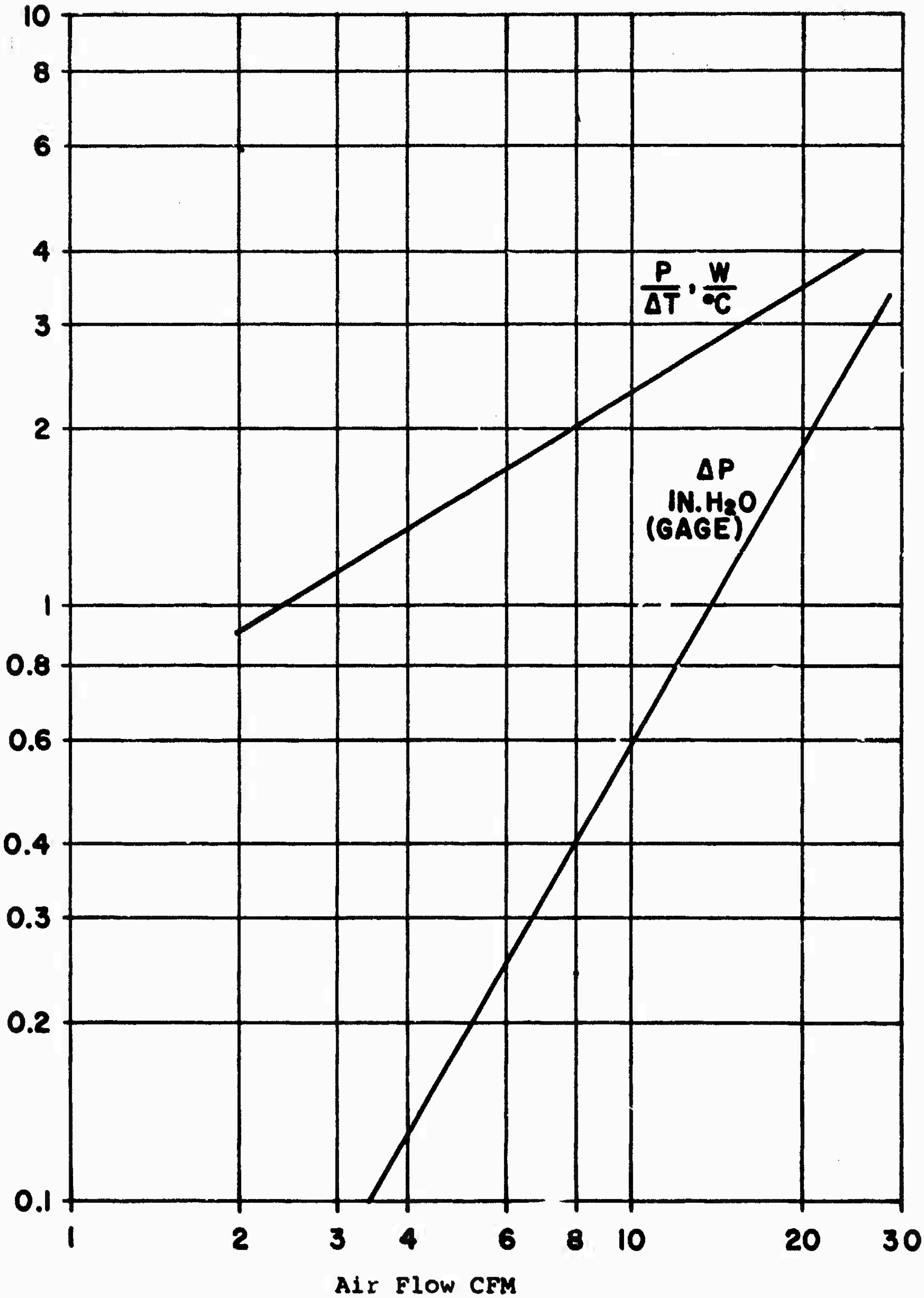


FIGURE 7. Anode Cooling Characteristics of the Experimental Type X2179F

TABLE 3. AIR COOLING OF 8590 & X2179F

Anode Dissipation P_p (Watts)	$P_p/\Delta T$ (a) (Watts/°C)	8590 Flow Rate (CFM)	8590 Pressure Head (in. H_2O)	X2179F Flow Rate (CFM)	X2179F Pressure Head (in. H_2O)
250	1.32	5.6	.24	3.8	.12
300	1.58	8.5	.49	5.2	.20
400	2.11	16.9	1.57	8.6	.45
500	2.63	28.4	3.84	12.5	.85

Notes: (a) $P_p/\Delta T = P_p/(225°C-35°C)$

VIDEO PULSE TESTING

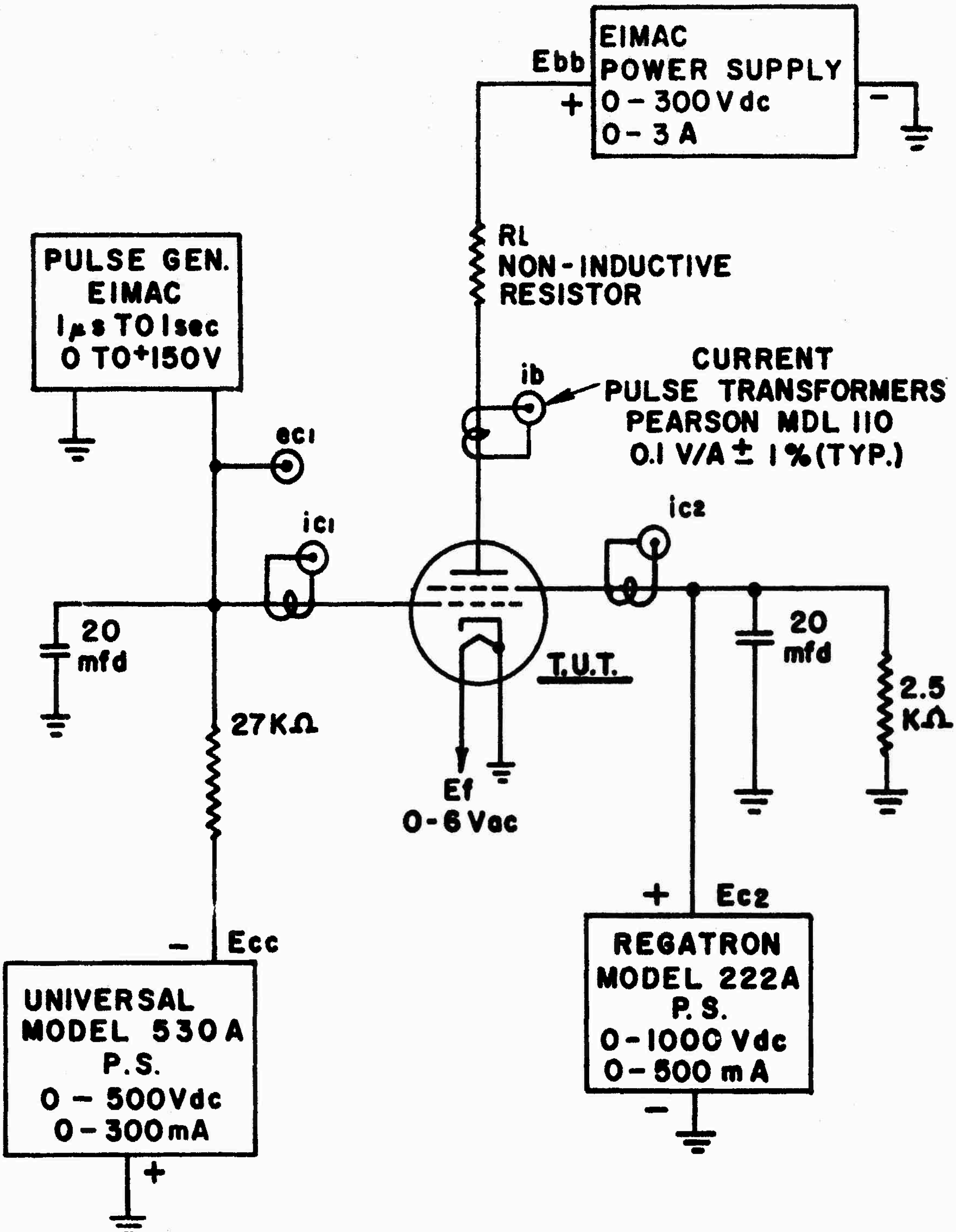
Video pulse tests were conducted on type 8590 (4CPX250K) tetrodes in order to evaluate the power handling capability of the cathode independently of effects brought about by rf operating conditions.

The tubes were operated in a grid-pulsed pulsed amplifier with dc screen grid and plate power supplies, with a series plate load resistor. A schematic diagram of the circuit is presented in Figure 8.

The operating conditions of the 8590 tubes were adjusted so that the pulse current and electrode dissipation levels equalled or exceeded those required for operation in the pulsed broadband rf amplifier.

Test Procedure

The tubes were selected from production lots of 8590 tetrodes and were tested for conformance to MIL-E-1/1670A. They were then installed in the TUT (Tube-under-test) socket of the video test set and all voltages were applied after a filament warmup time of 2 minutes (minimum). Test variables including pulse current were read and recorded at 24 hour intervals for the first hundred hours and at increasing intervals after that until the test was concluded. The operation of the TUT was checked each working day during the life tests. At the conclusion of the test, the parameters of the tube specification sheet were measured and compared with the original values.



VIDEO TEST SET
SCHEMATIC DIAGRAM

FIGURE 8. Video Test Set Schematic Diagram

Test Results

Five tubes were operated in the first test series. The test conditions common to all five tubes were:

DC plate voltage, Eb,	1900	volts
DC screen voltage, Ec2	425	volts
Peak plate current, i_b,	2.4 to 2.7	amperes
Series load resistance, R_L,	440	ohms
Filament voltage, Ef,	6.0	volts ac

They were operated at pulse widths from 10 to 40 milliseconds, duty factors of 0.06 to 0.15. These parameters are listed on the summary below, Table 4

TABLE 4. VIDEO TEST SUMMARY

Serial No.	Pulse Width (ms)	Duty Factor	Ib[a] (Arms)	Operating Time (Hours)
D4MK-5971	10	0.10	0.75	729
D4MK-6007	10	0.10	0.75	430
D4MK-5913	10	0.06	0.66	1735
D4MK-5851	10	0.10	0.80	2613
D4MK-5908	10	0.15	0.91	1200

[a] Ib is expressed in rms amperes as defined by the equation $I_b rms = i_b \times \sqrt{Du}$ where i_b is the peak plate current during the pulse and Du is the duty factor of the pulse.

Tubes DMK-5913, 5851, and 5908 were still operating satisfactorily when removed from test and were within limits of the tube specifications.

Tube No. 5971 failed, with heavy arcing, at 729 hours. The tube was opened and the cathode and grid showed evidence of arcing and loss of cathode coating.

The bias supply in the test set failed, causing the destruction of tube number D4MK-6007 after 430 hours of operation with no degradation.

A sixth tube, Serial No. D4MK-2142, was operated under the following conditions:

Eb	2000 volts dc
Ec_2	500 volts dc
R_L	25 ohms
I_b	3.7 Amperes
Pulse width	20 milliseconds
Duty factor	0.06
Ib	0.91 Amperes rms

for 3176 hours. During this time, the peak plate current, i_b, decreased 9 percent. The plate dissipation was 440 watts with no indicated screen grid dissipation and one watt of control grid dissipation. The test was terminated by destruction of the tube by loss of vacuum and arcing.

Following these tests, four additional type 8590 tetrodes were tested at higher voltage:

Eb	2700 Vdc
Ec_2	600 Vdc
R_L	25 ohms
Pulse length	20 milliseconds
Duty factor	0.06

The pulse plate current was adjusted to higher levels and the anode dissipation was much higher than the 250 watt rating, as shown in the table below.

TABLE 5. VIDEO TEST SUMMARY

Serial Number	Peak Plate Current (a)	RMS Plate Current (Arms)	Plate Dissipation (Watts)	Operating Time (Hours)
6APK-1439	4.6	1.13	680	673
H5LK-5916	4.7	1.15	700	41
D4MK-5841	5.1	1.25	720	44
D4MK-5853	3.5	0.85	430	1027

Tubes 6APK-1439 and D4MK-5841, developed envelope leaks as a result of excessive anode and anode seal temperature. D4MK-5916 suffered an equipment failure (loss of bias) and lost all cathode emission.

The anode current of the last tube of this group, D4MK-5853, was reduced to 3.5 amperes peak, 0.85 amperes rms and operated for 1027 hours with no apparent degradation.

The import of the video test series is that the video (peak) and rms current capability of the type 8590 is well in excess of the specification ratings for operating times of several hundred hours. The average operating time of seven tubes with rms current levels of 0.66 to 0.91 amperes, was 1558 hours; four of these seven tubes were still operable when testing was terminated.

DESIGN OF THE CAVITY

One of the requirements of this contract was to deliver a cavity capable of operating at the following conditions:

peak power output = 10kw

duty factor = 0.06

average power output =600W

operating frequency = 435MHz

Bandwidth at -1dB = 30MHz minimum

Because a cavity design was already available capable of 10kw (peak) output at a frequency close to that specified and a bandwidth approaching that required, the most worthwhile direction of effort was to modify the design of this cavity to meet these requirements.

Calculations, using 8590/4CPX250K output capacity and constant current curve data, showed that the desired power output and bandwidth were possible when a double tuned output circuit was used. A bandwidth of 30 MHz at the -1dB points was obtained. with a doubled tuned output circuit having a primary to secondary Q ratio of 1.5 to 1 and set to provide a tube load resistance of 1057 ohms. The response was Chebyshev with a 1/4 db dip at the center frequency. The peak plate voltage swing was 4848 and the plate current was 2.9a. The power output requirement was met by the 8590 at a plate voltage of 5500V.

The cavity to be modified had been designed for a system in which the peak power output was 10kw and the average power output was 50 watts. The cavity after modification produced the

same peak power output but the average output increased to 600 watts, an increase of twelve times. With no change in peak power requirement there was no change needed in voltage hold-off of the various capacitors and transmission line sections. Much improved cooling of the tube and cavity probably was needed because of the twelve times increase in average power. The cavity dimensions appeared to be adequately large to handle the average power when compared to an amplifier operating at that CW output.

The cavity was first changed from the original operating frequency, 442 MHz, to the new one, 435 MHz, by increasing the height of the anode resonator by 7/16 inch. This was done in preference to adding anode to ground capacity, because the additional capacity would have increased the stored energy of the resonator and thus narrowed the bandwidth with the same tube plate load resistance.

The required bandwidth, 30 MHz at -1dB was obtained by adjusting the coupling loop size between the anode resonator (primary) and the coupling resonator (secondary), and by increasing the characteristic impedance of the quarter wave line forming the coupling resonator. These adjustments were made using cold frequency sweeping techniques which allowed changes to be made to the cavity in a minimum of time.

To improve the average power capability of the cavity amplifier, the air cooling of the tube and cavity was changed. In the original cavity, cooling air was blown through the tube anode into the cavity chamber and exhausted through holes in the cavity wall. This created no problems as the tube anode dissipation was approximately 40 watts. However, at the highest duty condition tube anode dissipation was approximately 500 watts. To avoid blowing the hot air from the tube anode into the cavity, the direction of air flow was reversed. Air was blown into the cavity by means of a plenum chamber and exhausted through the tube anode cooler. This was effective and it was possible to operate at full duty.

TEST PROCEDURES

The test setup used to measure tube and amplifier performance is shown by Figure 9, Block Diagram - RADC Test Setup.

The rf drive signal originates at a Hewlett-Packard 608C signal generator set to the output frequency of 435 MHz. The signal is fed into an Anzac MD-143 balanced modulator used as a switch. The pulse generator turns on the MD-143 for the desired pulse length. Used in this way the MD-143 assures that the drive signal is at least 35 dB down from the input signal

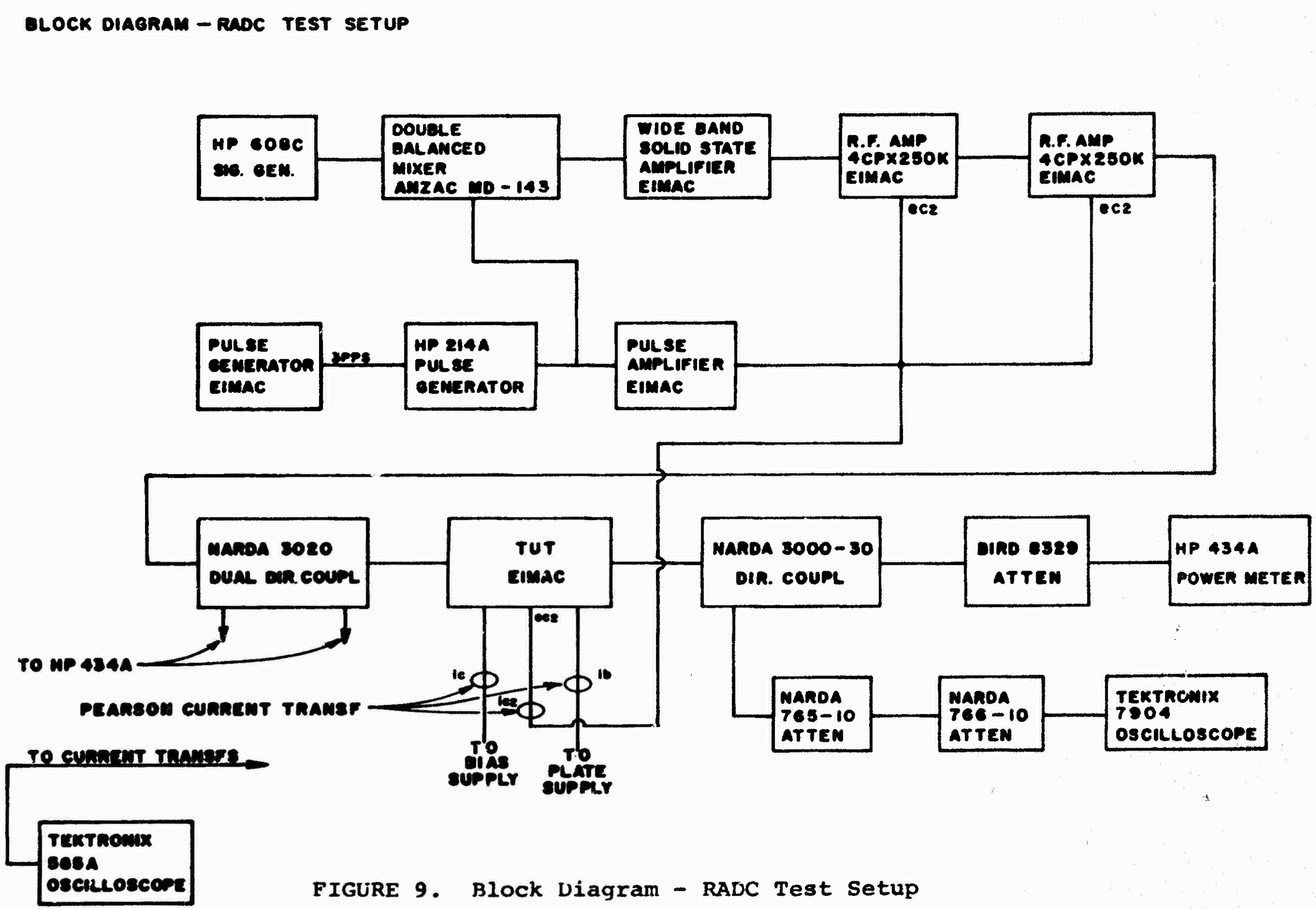


FIGURE 9. Block Diagram - RADC Test Setup

during the interpulse period. The pulsed rf signal is then fed into a wide band high gain solid state amplifier producing about 10 watts peak output power.

The 10 watt peak signal is then fed into two cascaded rf amplifier stages using 4CPX250K tubes. These two stages have fixed plate and grid bias voltages. The screen voltage is zero during the interpulse period and the tubes are cut off. When the rf signal is pulsed on, the screens are pulsed positive to about 800v for most test data runs.

By using this pulsing arrangement (a 35 dB switch plus three cascaded amplifier stages all cut off during the interpulse period), the rf power output during the off time is negligible. This is necessary because both power output and drive are measured with a Hewlett-Packard 434A calorimetric power meter. The HP434A averages the power reading over a long time period. Thus any power leaking through during the interpulse period would add to the power measured during the ON time, increasing the average power reading. Because peak rf power output is calculated from the average power output measurement an error would result. However with good power output suppression during the OFF time the calculation of peak rf power from average power measurement and duty is a valid procedure.

Data recorded during rf testing are as follows:

Eb	=	DC plate voltage to the TUT
ib	=	Plate current during the pulse
e_{c2}	=	Screen voltage during the pulse
i_{c2}	=	Screen current during the pulse
Ec1	=	DC grid bias voltage
ic1	=	Grid current during the pulse
PO	=	Average rf power output from the TUT
PD	=	Average rf drive power to the TUT
prr	=	Pulse recurrent rate in pulses per second
tp	=	Pulse length in milliseconds

Performance data calculated from recorded data are as follows:

Du	=	Duty
		$Du = \frac{tp \times prr}{1000}$
pin	=	Anode power input during the pulse
		pin = Eb x ib, watts
po	=	rf power output from the TUT during the pulse
		PO/Du, watts
pd	=	rf drive power to the TUT during the pulse
		PD/Du, watts
Gain	=	Gain of the TUT
		$Gain = \frac{po}{pd}$
eff	=	Efficiency of the TUT in percent
		$eff = \frac{po}{pin} \times 100\%$
pp	=	Tube anode dissipation during the pulse
		pp = (pin - po), Watts
Pp	=	Average tube anode dissipation
		Pp = pp x Du Watts

RF Test Results

Twenty-two different tubes were evaluated in the rf test setup. Three type X2179E, twelve 8590/4CPX250K, two X2179F's and five X2179G's. The rf test results are summarized in Table 6 - RF Test Results.

X2179E

The X2179E's were operated in the second driver stage before the TUT had been completed. Plate voltage was therefore limited to 3KV. The pulse length was 20ms and the duty 0.06. One of the tubes, Serial No. E5C-230, had poor emission and did not improve during a 30 hour run. Of the two remaining, E40K-6365 was run for 30 hours during which two tube arcs occurred. Even though the power supply had a large capacitor for energy storage and no crowbar was being used, the tube showed no deterioration after the arcs. The third tube, Serial No.E4MK-3564, was run for 160.2 hours with no arcs.

TABLE 6. RF TEST RESULTS

Type & Ser: No.	Pulse Width ms	Pulse Duty	ib a	po kw	Operating Time Hours	Remarks
4CPX250K H5LK-5917	0.25	0.005	3.6	10.8	2	No arcs.
4CPX250K H5LK-6184	0.25	0.005	3.7	11.2	1-1/2	Arced 5 min. after first turned on. Then ran OK after more aging.
4CPX250K H5LK-6183	1	0.003	3.5	10.7	40	Ran with no arcs for 40 hrs. Arced immediately when duty increased to 0.006, 2 ms pulse. Larger blower installed.
4CPX250K H5LK-6183	0.1	0.06	3.4	10.9	9	Arced after 1hr. Afterward no arcs for 8 hours.
4CPX250K H5LK-6119	0.1	0.06	3.3	10.3	2	3 arcs in 2 hr. run.
4CPX250K D4MK-5908	0.1	0.06	3.3	11.2	4-1/2	2 arcs during 4-1/2 hr. run. Tube previously run 1277 hrs. in video test.
4CPX250K H5LK-6030	10	0.03	3.5	9.7	1	Tube arced after 15 min. Had run OK previously at pulse lengths up to 5ms.
X2179F J5NK-7841	0.25	0.005				Many arcs. Would not run.

TABLE 6. RF TEST RESULTS Contd.

Type & Ser:No.	Pulse Width ms	Pulse Duty	ib a	po kw	Operating Time Hours	Remarks
X2179F J5NK-7842	1	0.003	3.7	10.1	7	No arcs for 7 hour run.
" "	2	0.006	3.8	10.0	5	Arced 2 times during run.
" "	1	0.02	-	10.6	1-1/2	No arcs.
" "	0.25	0.02	-	11.1	1/3	No arcs.
" "	0.25	0.06	-	10.2	1/3	No arcs.
" "	10	0.03	-	10.2	2	No arcs.
X2179E E40K-6365	20	0.06	1.9	2.56	30	Eb=3KV. Arced two times.
X2179E E5C-230	20	0.06	-	1	30	Eb=3KV. Poor cathode emission. Ran 30 hrs. with no change.
X2179E E4MK-3564	20	0.06	1.7	2.14	160.2	Eb=3KV. No arcs.
NOTE: All the following tubes operated at Eb = 5.5KV.						
4CPX250K H5LK-6164	2	0.006	3.3	10.4	1	Arced once.
" "	3	0.009	4.2	11.5	1/12	Arced after 5 min. Arced 4 more times. Then changed tubes.
4CPX250K H5LK-6163	0.5	0.0015	4.0	12.0	1	No arcs.
" "	10	0.03	2.9	9.2	1/4	Arced after 3 min. Then ran OK.

TABLE 6. RF TEST RESULTS Contd.

Type & Ser:No.	Pulse Width ms	Pulse Duty	ib a	po kw	Operating Time Hours	Remarks
4CPX250K H5LK-5872	2	0.006	3.3	10.5	1/4	No arcs. Tube arced when duty increased to 0.06 at 1/10ms length.
4CPX250K H5LK-5875	5	0.015	3.5	10.48	2	No arcs.
" "	0.1	0.06	3.2	9.34	-	Tube ran only short time before it arced.
4CPX250K H5LK-5895	1	0.003	3.7	9.66	1/4	Arced after 15 min. When duty increased to 0.06, 1/10ms pulse, tube arced before data noted.
4CPX250K H5LK-5916	1	0.003	-	-	-	Tube arced after 2 min. Aging 3 hrs. at reduced Eb made no improvement.
X2179G A6FK-4540	10	0.03	3.5	10	5.3	No arcs.
X2179G A6FK-4541	10	0.03	3.4	10	3.3	No arcs.
X2179G A6FK-4542	10	0.03	3.4	10	3.1	No arcs.
X2179G A6FK-4543	10	0.03	3.5	10	8.3	No arcs.
X2179G A6FK-4544	10	0.03	3.5	10	2.7	No arcs.

8590

Of the twelve 8590/4CPX250K's. Serial Nos. H5LK-5917 and H5LK-6184, were run at low duty with a 0.25ms pulse length. In a combined 3-1/2 hours running time only one arc occurred. The remaining ten tubes were run with pulse lengths of 1ms to 10ms or with a 1/10ms pulse at 0.06 duty. Until the cooling of the TUT was improved very little success was had in running at the highest duty of 0.06. However, H5LK-6163 operated with a 10ms pulse, 0.03 duty, for 15 minutes with only one arc, that one occurring 3 minutes after the run began. H5LK-5875 ran 2 hours with no arcs while operating with a 5ms pulse, 0.015 duty. Also H5LK-6183 ran for 40 hours with no arcs running with a 1ms pulse at 0.003 duty.

After improving the TUT cooling H5LK-6119 and D4MK-5908 were run with a 0.1ms pulse at 0.06 duty. In a 2 hour period 6119 arced 3 times, while 5908 arced 2 times in 4-1/2 hours. D4MK-5908 had been run previously in the video pulse test equipment for 1277 hours.

X2179F

Two X2179F's were evaluated. J5NK-7841 would not run at 5.5KV plate voltage because of numerous arcs. J5NK-7842 was run for just over sixteen hours. It was initially run for seven hours with no arcs with a 1ms pulse length and a duty of 0.003. Then for five hours with two arcs occurring when using a 2ms pulse at 0.006 duty. The tube then was subjected to a series of operational tests to demonstrate compliance with the contract Statement of Work. A representative of Rome Air Development Center witnessed and accepted the data. The tests performed were as follows:

1. 10.63kw output power with a 1ms pulse length, a pulse recurrence rate of 20 pulses per second and a duty of 0.02. The time for the run was 1.5 hours.

2. 11.05kw output power with a 250 microsecond pulse length a pulse recurrence rate of 80 pulses per second and duty at 0.02. The time for the run was twenty minutes.

3. 10.17kw output power with a 250 microsecond pulse length, a pulse recurrence rate of 240 pulses per second and a duty of 0.06. The time for this run was two hours.

4. 10.23kw output power with a 10 millisecond pulse length, a pulse recurrence rate of three pulses per second and a duty of 0.03. The time for this run was two hours.

In all the tests run above, the TUT amplifier power gain was greater than 10dB.

X2179G.

Five type X2179G's were tested. All produced 10kw peak output at more than 10 dB gain. The running time for each tube varied from 2.7 to 8.3 hours, the total for all five was 22.7 hours, with no arcs occurring. This testing was done with 10ms pulse at 0.03 duty.

During testing it was found necessary to age the tubes beyond the aging normally done in production. Production aging procedure calls for 0.25ms pulse length at 0.005 duty. To avoid destructive arcing during tests tubes were run in the TUT at gradually increasing pulse lengths and plate voltage for a period of several hours. The special aging procedure could be done at relatively low duty, the rep. rate being 3 pps. However, to improve the capability of a tube to run at long pulse lengths the procedure had to be carried out to those pulse lengths. If a tube was to be tested with a 10ms pulse, it had to be aged with that pulse length.

RF Aging Schedule Used for X2179G's

E_{c1} = =110V F = 435MHz prr = 3pps

Adjust ec_2 and pd for conditions listed below.

Eb	Ef	ib	Ib_o	po	tp	Time
KV	A	a	a	kw	ms	Hours
4	6.0	2	-	-	1	1
5	6.0	3	-	-	1	1
5.5	6.0	3.5	0.8	10	1	1
5.5	6.0	3.5	0.8	10	2	1
5.5	6.0	3.5	0.8	10	5	2
5.5	6.0	3.5	0.8	10	10	2
5.5	5.4	3.5	0.8	10	10	1

NOTE: If tube arcing occurs at any level the tube should be run with lower plate voltage and current for 15 minutes before attempting to run at the next level.

3. CONCLUSIONS

The tests performed during the program indicate that it is possible to operate the 8590/4CPX250K at much longer pulse lengths and higher duty than had previously been believed feasible. Operation at 435 MHz with a peak power output of 10kw and 10dB power gain was demonstrated. This performance was achieved with a pulse length of 10 ms and a 0.03 duty factor; also at a pulse length of 0.1 ms and 0.06 duty. The inability to cool the 8590/4CPX250K is more of a deterrent to long pulse length and high duty factor operation than is the cathode. The size of the blower to cool the 8590 is impractically large for anode dissipations on the order of 500 watts. The relative blower power (product of CFM x ΔP) required by the 8590 is 10 times the X2179F requirement.

The X2179F showed improved performance over the 8590/4CPX250K in the ability to operate at high duty factors. One X2179F was run continuously for two hours with a 10 ms pulse, 0.03 duty, without any arcs while producing 10 kw peak power output at 435 MHz with 10 dB power gain. It was also operated for 20 minutes without arcing using a 0.25 ms pulse at 0.06 duty.

The X2179G, which incorporated the high duty capability of the X2179F with a CPC cathode, performed well. All five of the tubes tested developed 10kw peak power without arcing. These tubes were tested with a 10 ms pulse, 0.03 duty for a total running time over 22 hours. The new anode cooler design permits operating the X2179G at 500 watts dissipation with a practical blower size. The Provisional Specification sheet for the X2179G has in it a minimum anode dissipation rating of 500 watts with a recommended air flow of 15 CFM (at 1.2 inches, gage, pressure drop). This will result in a minimum anode temperature of 225°C with 50°C air supply at sea level.

4. RECOMMENDATIONS

Testing done in the rf test setup was all of very short duration. The tests show that the 8590/4CPX250K can operate with long pulses, and in high average dissipation versions, the X2179F and X2179G can operate with high duty factors. It is recommended that life testing be done to determine how this type of operation affects the life expectancy of the tube.

The tests indicate that to run a tube with long pulses it is necessary to use adequate aging schedules. The tube cathode may be damaged if the aging schedule does not use pulse lengths as long, or longer, than that at which it will be run. It is therefore recommended that tubes intended for long pulse operation be aged for the specific application.

It is necessary to protect the tube from damage due to the dumping of a large amount of energy from storage capacitors when the tube arcs. Large capacitors are needed in the plate supply to support long pulses. It is recommended that this stored energy in the capacitors be prevented from being dissipated in the tube by means of a crowbar or very fast means of interruption such as a high speed fuse.

APPENDIX 1

PROVISIONAL TEST SPECIFICATION
TYPE X2179G

PROVISIONAL TEST SPECIFICATION

ELECTRON TUBE, TRANSMITTING TETRODE
EXTERNAL ANODE, FORCED-AIR COOLED

TYPE X2179G

DESCRIPTION: Tetrode, coaxial-base, with F1 = 500 MHz
See Figure 1
Mounting Position: Any
Weight: 4 ounces (113 grams) nominal

ABSOLUTE MAXIMUM RATINGS:

Parameter:	Ef	Eb	Ec1	Ec2	ec2	Ib	ib	tp	Du
Units:	Vac Note 1	Vdc	Vdc	Vdc	v	mAdc	a	µs	---
C Telegraphy:	6.0±5%	2500	-250	500	---	250	---	---	---
Grid Pulsed C rf Amp. :	6.0±5%	5500	-250	---	1000	---	Note 2	Note 2	Note 2
TEST COND :	6.0	1000	Adj.	300	---	150	---	---	---

ABSOLUTE MAXIMUM RATINGS:

Parameter:	Pg1	Pg2	Pp	Anode Core & Seals T	tk	Cooling
Units:	W	W	W	°C	sec	--- Note 3
C Telegraphy:	2.0	12	500	250	30	---
Grid Pulsed C rf Amp. :	2.0	12	500	250	30	---
TEST COND :	---	---	---	---	120	Note 4

METHOD OR PAR. references: MIL-E-1 & MIL-STD-1311

Envelope: Metal & Ceramic

METHOD OR PAR.	REQUIREMENT OR TEST	CONDITIONS	AQL%	INSP. LEVEL	SYMB.	LIMITS Min	Max	UNITS
	General							
4.8.5	Holding Period		---	---	t:	72	---	hrs
---	Cathode	Oxide-coated (CPC) unipotential	---	---	---	---	---	---
	Quality Conformance Inspection - Part 1 (Production) Note 5							
D-30(a), 40, 60	Visual & Mechanical Inspection Criteria		---	---	---	---	---	---
1261	Electrode Voltage (grid)		0.65	II	-Ec1:	35.0	48.0	Vdc
1256	Electrode Current (screen)		0.65	II	Ic2:	-7.0	+3.0	mAdc
1266	† Total Grid Current	Eb = 2000 Vdc; Ec1/Ib = 250 mAdc	0.65	II	-Ic1:	---	15	µAdc
1266	Pri.Grid Emission (control)	Ic1 = 70 mAdc; t = 15; anode & g2 floating	0.65	II	-Isg1:	---	25	µAdc
1266	Pri.Grid Emission (screen)	Ec1 = 0 Vdc; t = 15; Ic2 = 100 mAdc; anode floating	0.65	II	-Isg2:	---	250	µAdc

METHOD OR PAR.	REQUIREMENT OR TEST	CONDITIONS	AQL%	INSP. LEVEL	SYMB.	LIMITS Min	Max	UNITS
	<u>Quality Conformance Inspection - Part 1 (Production) Note 5 (Cont'd)</u>							
1372	Current Division	Eb = Ec2 = 250 Vdc; Ec1 = -100 Vdc;	0.65	II	egk:	5.0	16.0	v
		prr = 11 ± 1 pps;			ic1:	---	200	ma
		tp = 4500 μs min; egk/ib = 1.0 a			ic2:	---	260	ma
	<u>Quality Conformance Inspection - Part 2 (Design) - Note 6</u>							
D-30(b)	Dimensions	Per Figure 1	6.5	S3	---	---	---	---
1301	Heater Current		6.5	S3	If:	3.1	3.6	Aac
1331	Dir. Interelectrode Capacitance (gnd grid connection)		6.5	S3	Cpk:	---	0.01	pF
					Cin:	13.0	16.5	pF
					Cout:	3.90	4.35	pF

METHOD OR PAR.	REQUIREMENT OR TEST	CONDITIONS	AQL%	INSP. LEVEL	SYMB.	LIMITS Min	LIMITS Max	UNITS
	<u>Quality Conformance Inspection - Part 2 (Design) - Note 6 (Cont'd)</u>							

---	Power Gain	F = 435 ± 5 MHz;
		Ec1= -100 to -200 Vdc;
		ec2 = 1000 v max;
		Eb = 5500 Vdc;
		Du = 0.03; prr = 3 pps;
		tp = 10 ms;
		pd = 1000 w maximum;
		ib = 3.7 a maximum;
		Ef = 5.4 Vac;
		See Note 7
			6.5	S3	po:	10.0	---	kw (useful)

	<u>Quality Conformance Inspection - Part 3 (Periodic) - Note 8</u>							
D-30(b)	Dimensions	Per Figure 1	---	---	---	---	---	---

NOTES

1. At frequencies above approximately 300 MHz it may be necessary to reduce heater voltage to compensate for rf transit-time heating of the cathode. This type of back-heating is a function of frequency, grid current, grid bias, anode current, duty cycle, and circuit design and adjustment. Heater voltage should be maintained within ±5% when long life and consistent performance are factors, but in no case should the heater be operated at less than 5.4 volts. The following derating voltages are shown as a guide:

Frequency (MHz)	Ef (volts)
300 or lower	6.00
301 to 400	5.75
401 to 500	5.50

2. Peak plate current (ib) may be considered as average during the pulse and must be limited to the values shown in Figure 2 and 3. In each case the equipment designer or operator has the responsibility of assuring that no maximum rating is exceeded.

3. Forced-air cooling must be provided for the base and anode. The maximum seal and anode core temperature ratings should not be exceeded. With a plate dissipation of 500 watts and an incoming air temperature of 50°C maximum at sea level, a minimum air flow of 15 cfm must be passed through the anode cooler. With power on the tube the static pressure drop across the anode cooler with an air flow of 15 cfm at 50°C at sea level is approximately 1.2 inches of water. The pressure drop will vary with the amount of escaping air, air temperature, and with the shape and construction of the air director. The pressure drop in most equipments can be expected to be considerably higher than 1.2 inches of water because of temperature and system losses caused by associated hardware such as contact collets, cavity, etc. The stem of the tube must be cooled by a portion of the anode air or by a separate air supply. Air flow should be applied before or simultaneously with electrode voltages (including the heater) and may be removed simultaneously with them. In cases where long life and consistent performance are factors, cooling in excess of minimum requirements is normally beneficial.

4. In all electrical tests involving application of heater voltage forced-air cooling of the tube shall be allowable.

5. These tests shall be carried out as standard production tests. Sampling per MIL-STD-105 may be used. The AQL for the combined defectives for attributes, excluding mechanical, shall be 1%. A tube having 1 or more defects shall be counted as 1 defective.

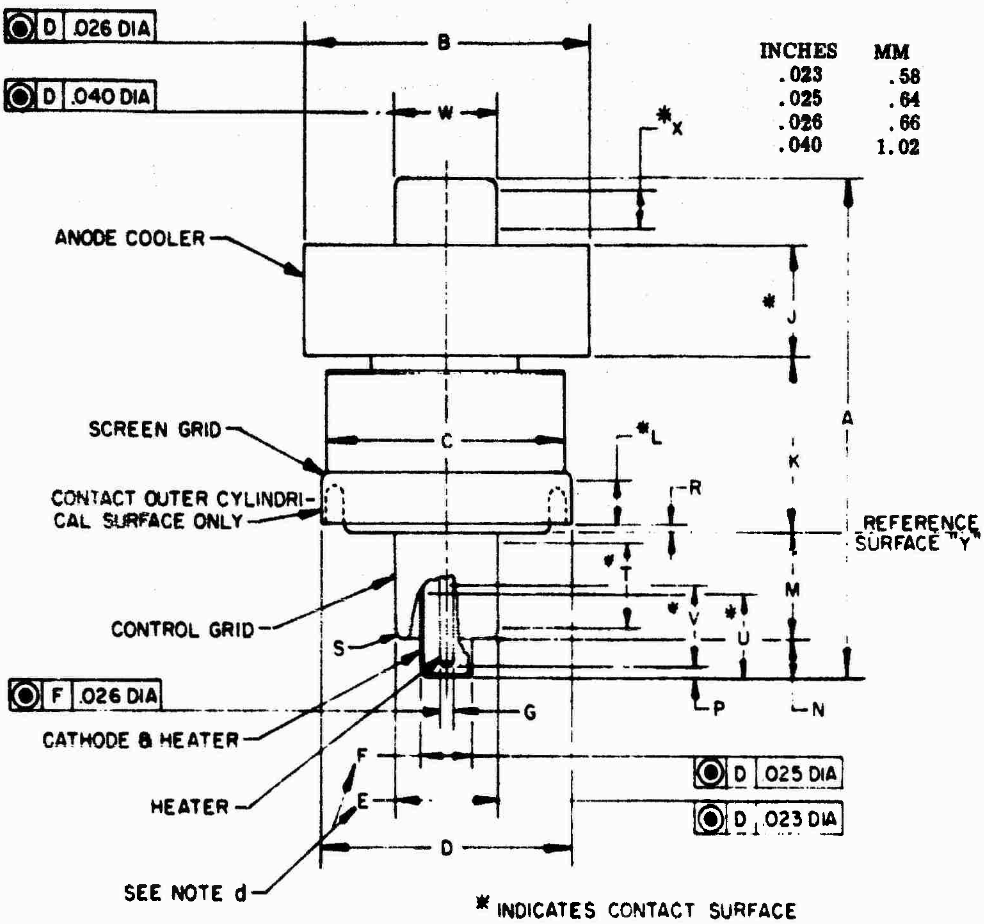
NOTES (Cont'd)

6. Sampling shall be in accordance with MIL-STD-105.

7. Test to be performed in cavity per Drwg. # TBS
During the test, cooling air need not be restricted to 15 cfm because of system losses. The cavity shall be tuned so as to have a 1 dB bandwidth of 30 MHz centered at 435 MHz.

8. Periodic testing shall be performed quarterly. A regular double sampling plan shall be used, with the first sample of three tubes with an acceptance number of zero, and a second sample of three tubes with a combined acceptance number of one. In the event of failure, the failing test will be made as a part of Quality Conformance Inspection Part 2, AQL 6.5, Inspection Level S3. The regular yearly double sampling plan may be reinstated after three consecutive samples have been accepted.

FIGURE 1 - Outline Drawing, Type X2179G



NOTES

a. The eccentricity values shown shall be considered as maximum values, and shall be checked on a Quality Conformance Inspection Part 3 (Periodic) basis.

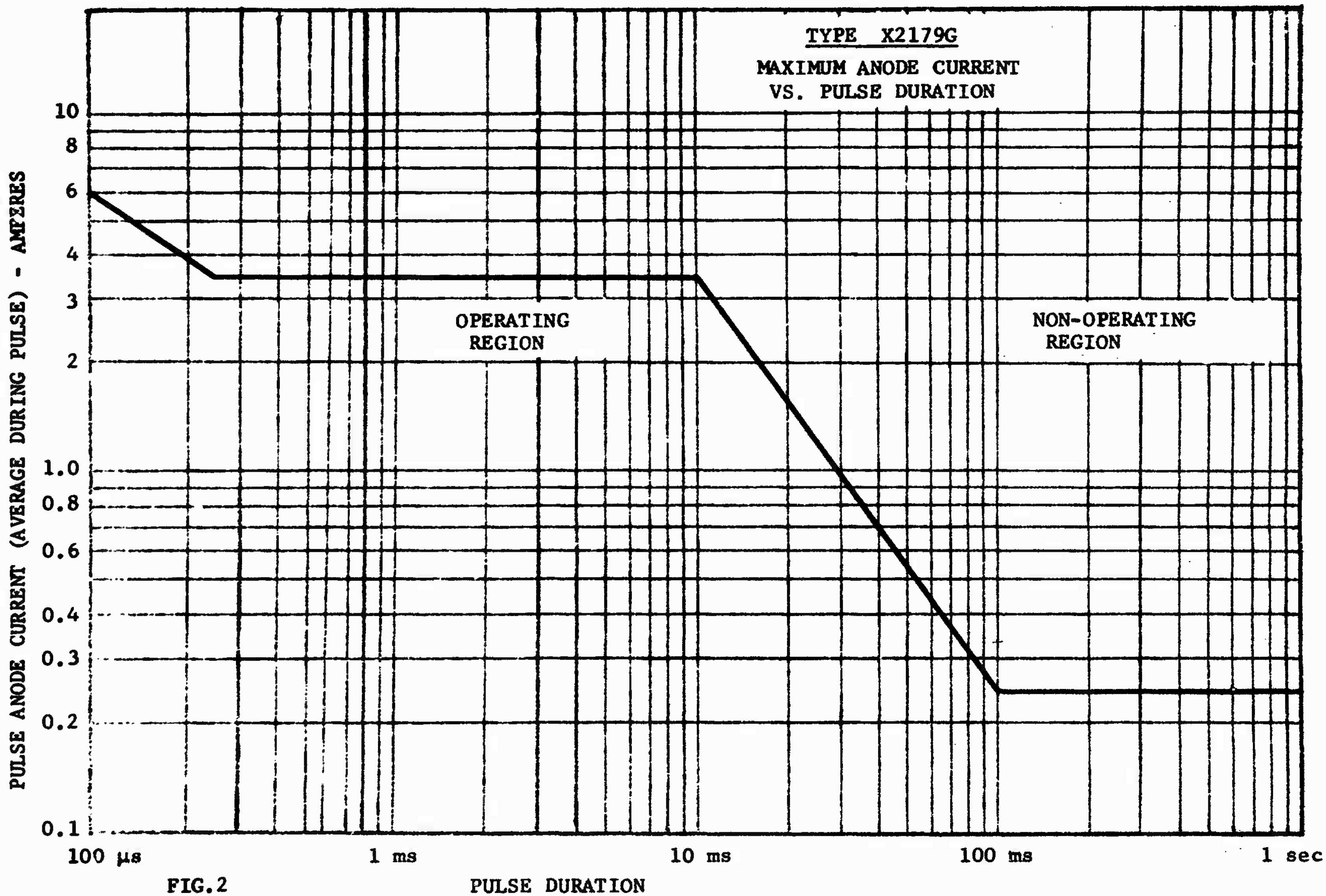
b. The tube shall be rotated on diameter D when eccentricity is being measured.

c. Surface Y shall be perpendicular to the measuring platform when eccentricity is being measured.

d. Average diamter of E shall be as noted, and may be out of round a total of 0.006 (0.15 mm). Average diameter of F shall be as noted, and may be out of round a total of 0.006 (0.15 mm).

DIM.	AQL	INSP. LEVEL	INCHES	
			Min.	Max.
Quality Conformance Inspection, Part 2				
A	6.5	S3	---	2.950
D	6.5	S3	1.415	1.435
Quality Conformance Inspection, Part 3				
B	---	---	1.615	1.640
C	---	---	---	1.406
E	---	---	0.588	0.597
F	---	---	0.318	0.325
G	---	---	0.091	0.095
J	---	---	0.710	0.790
K	---	---	0.940	0.990
L	---	---	0.187	---
M	---	---	0.520	0.560
N	---	---	0.235	0.265
P	---	---	0.032	0.082
R	---	---	---	0.040
S	---	---	---	0.171R
T	---	---	0.388	---
U	---	---	0.406	---
V	---	---	0.468	---
W	---	---	0.559	0.573
X	---	---	0.240	---

FIGURE 1 - Outline Drawing, Type X2179G (Cont'd)



TYPE X2179G
MAXIMUM ANODE CURRENT
VS. PULSE DURATION
10
8
6
4
3
2
1.0
0.8
0.6
0.4
0.3
0.2
0.1
OPERATING
REGION
NON-OPERATING
REGION
100 µs
1 ms
10 ms
100 ms
1 sec
PULSE DURATION
PULSE ANODE CURRENT (AVERAGE DURING PULSE) - AMPERES

FIG.2

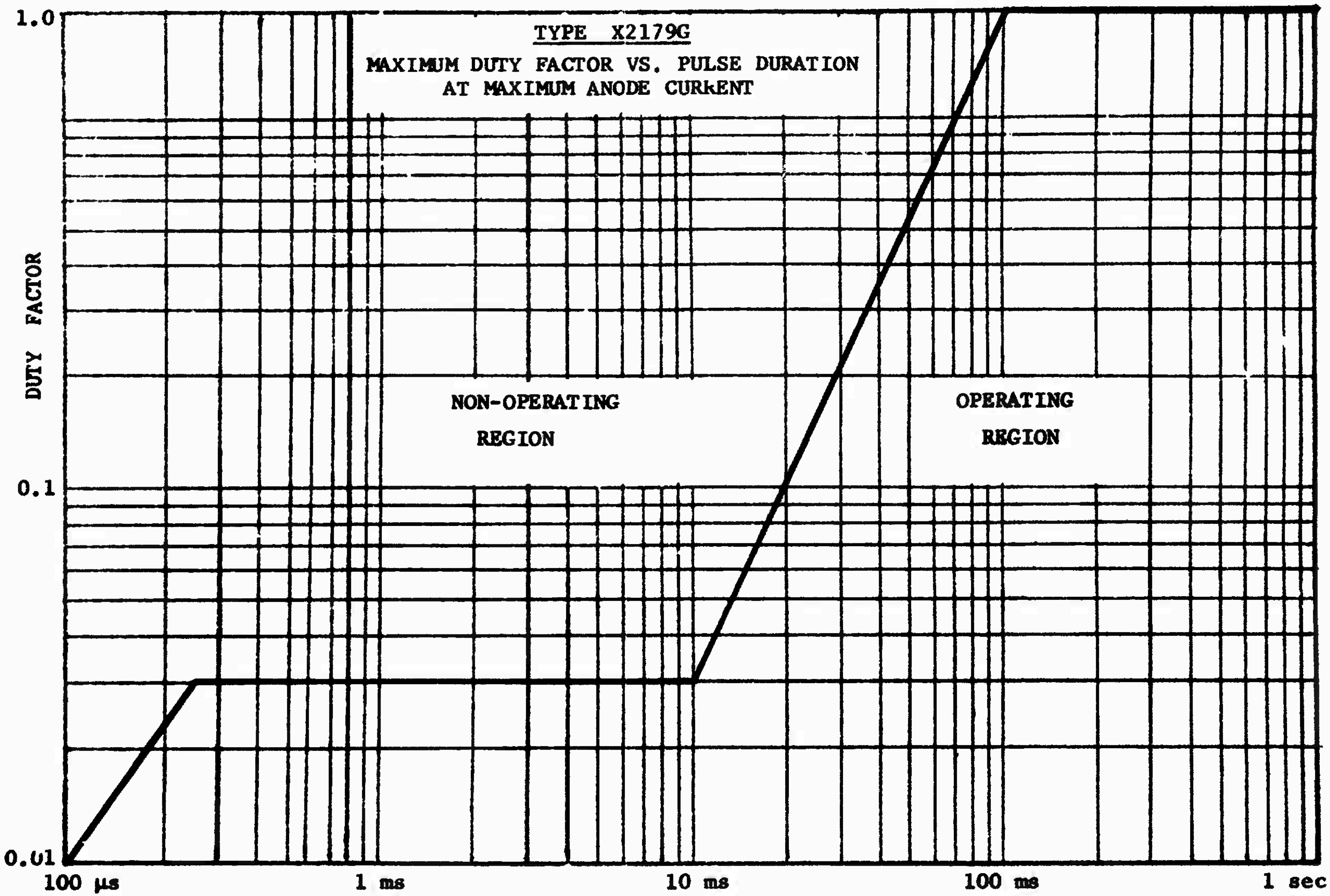
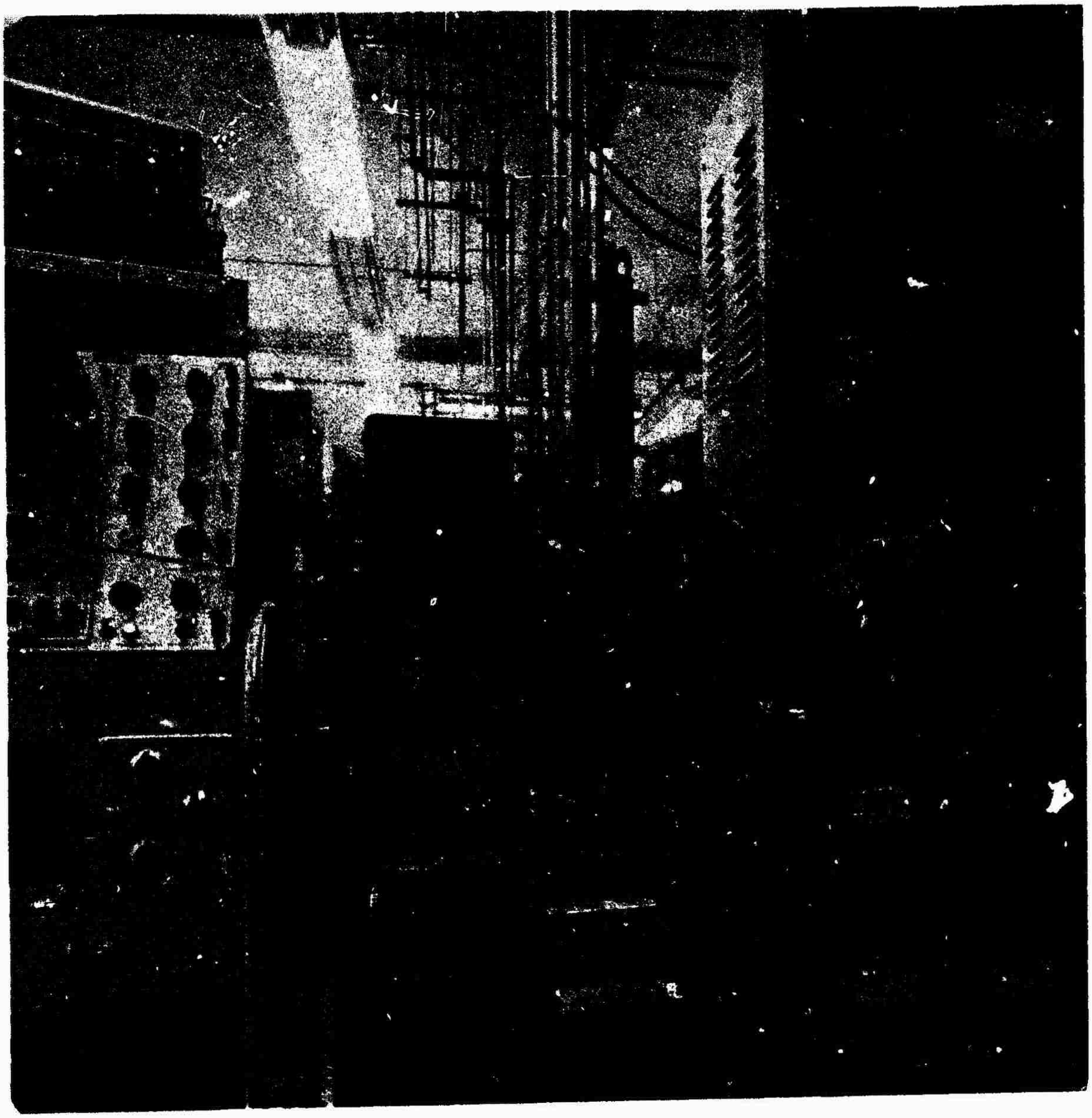

TYPE X2179G
MAXIMUM DUTY FACTOR VS. PULSE DURATION
AT MAXIMUM ANODE CURRENT
NON-OPERATING
REGION
OPERATING
REGION
DUTY FACTOR
1.0
0.1
0.01
100 µs
1 ms
10 ms
100 ms
1 sec
PULSE DURATION

FIG.3

APPENDIX 2

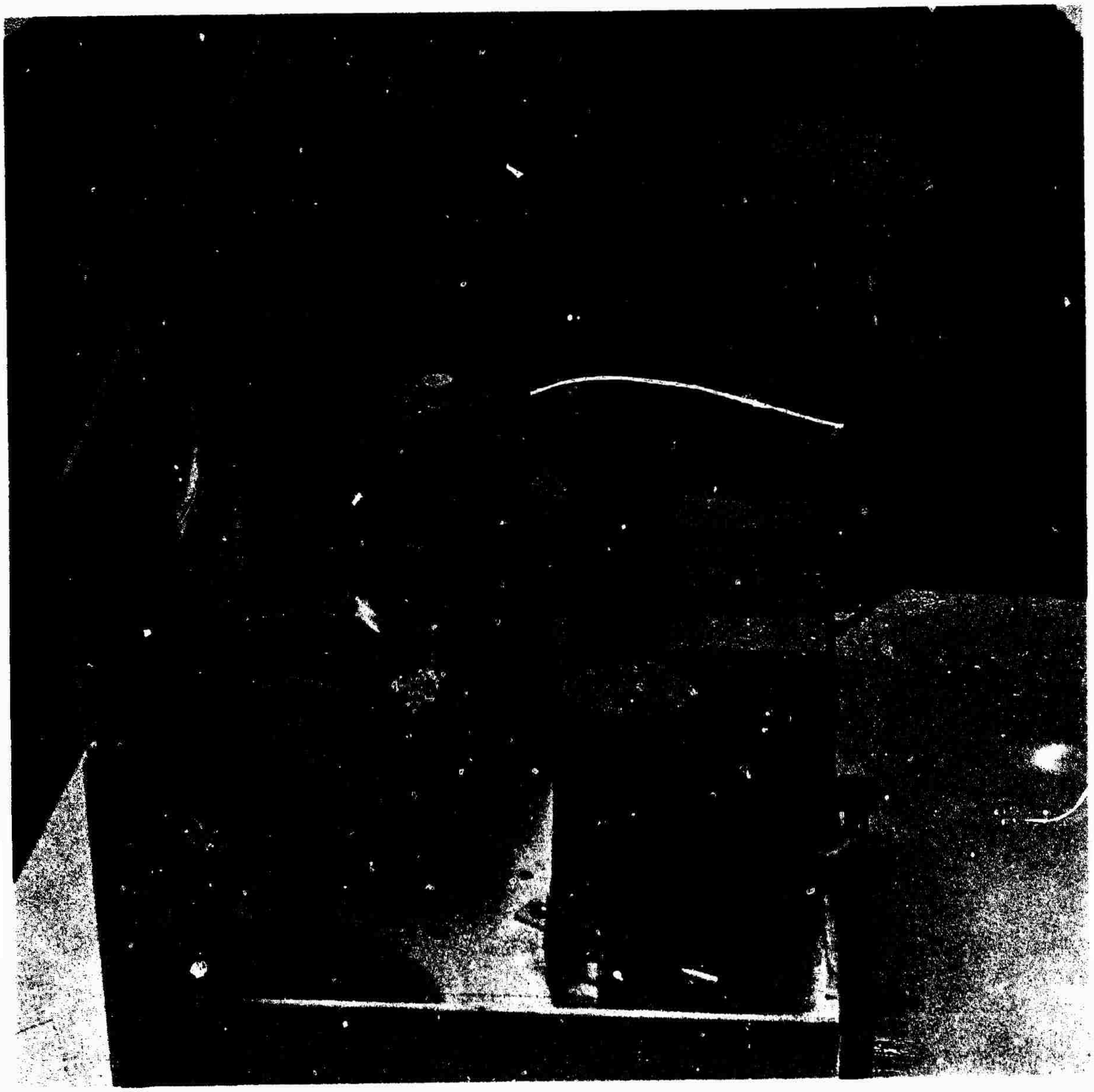
FIGURES 1 - 8

TEST POSITION AND EQUIPMENT



View of the test set-up used to conduct long pulse video life tests. The rack contains the TUT, the pulse driver and the associated screen and bias supplies. The plate supply is at center with the long pulse generator on top of it. The Tektronix scope is used to monitor the TUT plate, screen and grid pulse currents.

FIGURE 1.

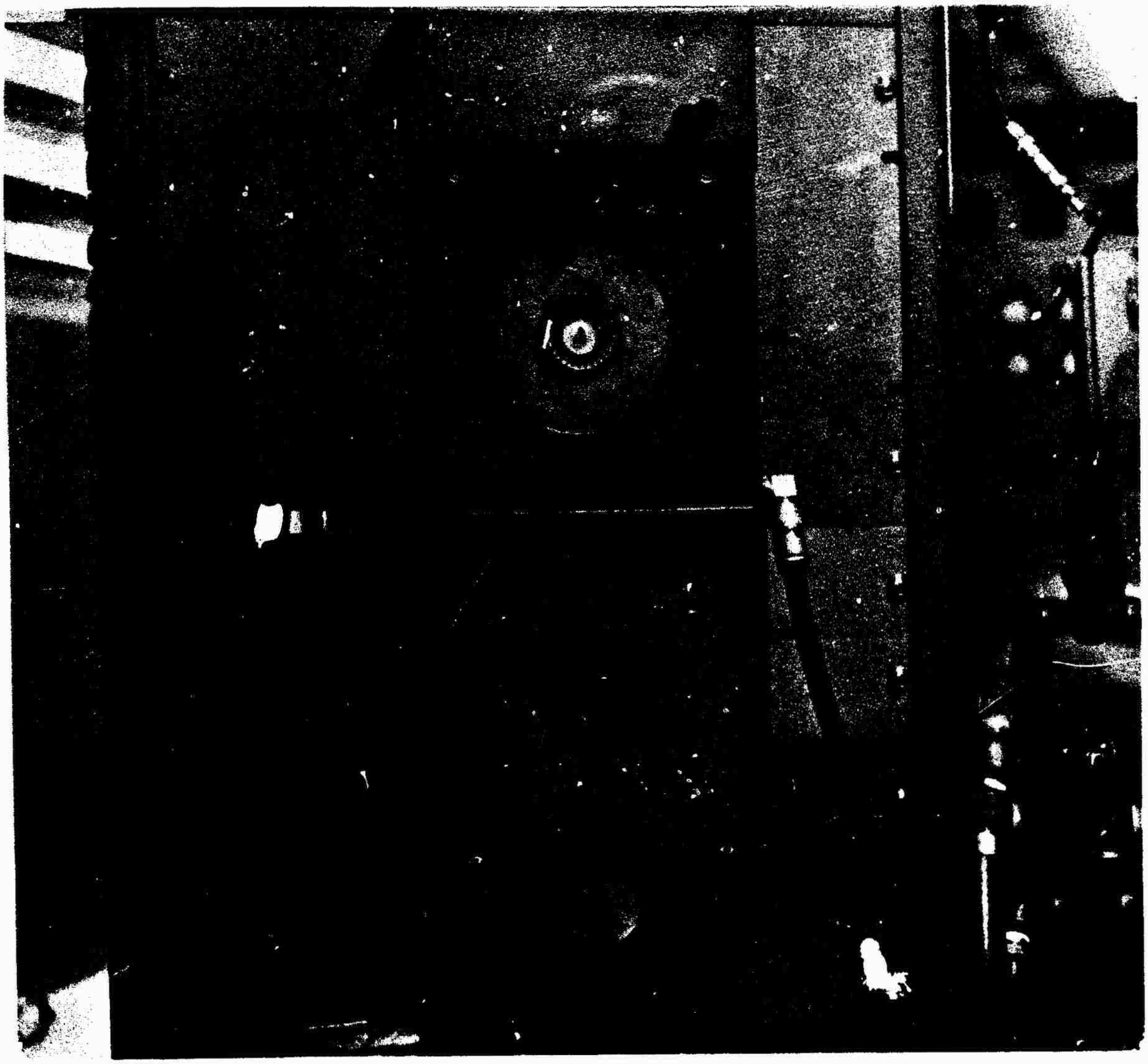


The TUT chassis used to make long pulse video life tests. The current transformer is used to measure pulse plate current.

FIGURE 2.

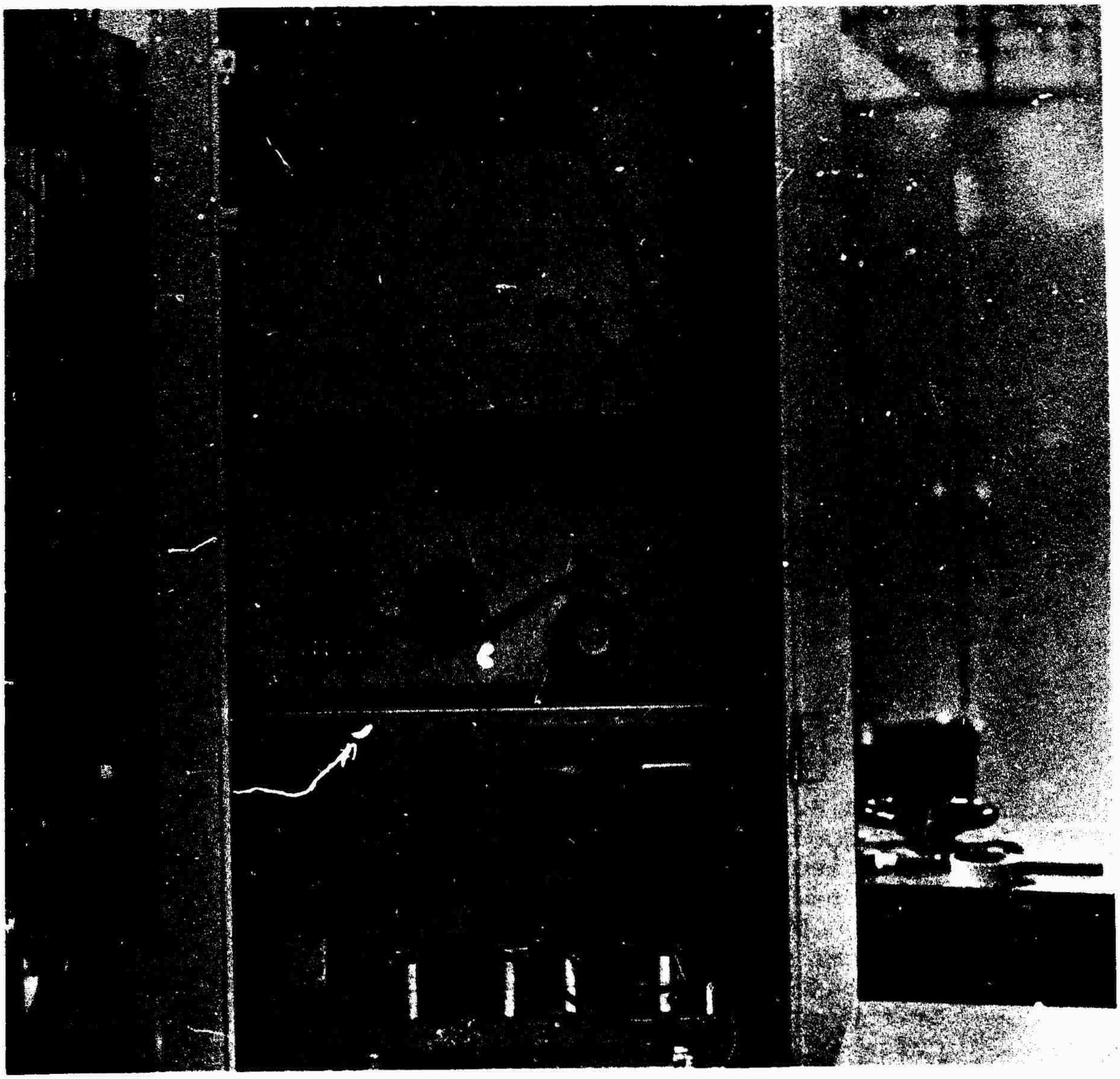
View showing the test position and equipment used to measure tube and cavity performance. The left hand rack contains the TUT, its heater and grid bias supply, blower, DC voltage and current meters for the TUT, pulse transformers to measure TUT electrode currents, crowbar for the TUT and at the top the pulse generator. The center rack contains the two RF driver and associated DC supplies primarily, and also the screen pulse for the TUT and the RF driver stages, and at the top the wide band solid state RF amplifier and balance modulator RF switch. The open rack at the right contains the Bird 30 db power attenuator and the HP608C set to 435 MHz. The directional coupler in the RF output coaxial line from the TUT to the Bird attenuator is used to provide an RF sample signal to the Tektronix 7904 scope shown at the right of the photo. The open rack also contains the HP434A power meter used to measure RF drive and output power.

FIGURE 3.



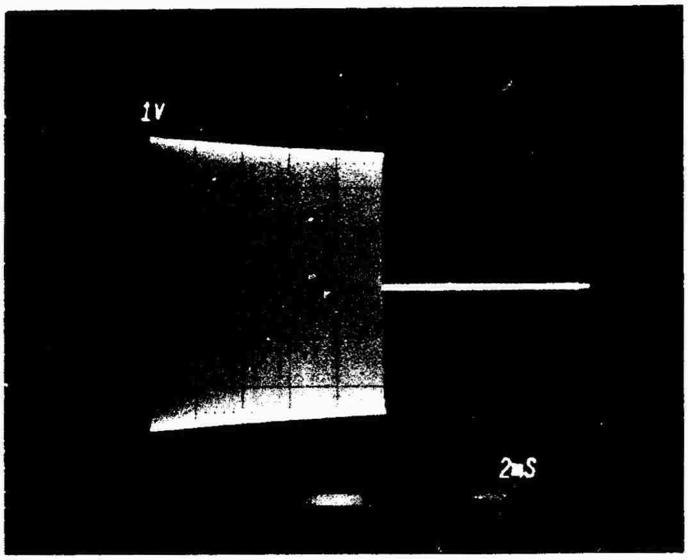
View of the TUT with an 8590/4CPX250K plugged into the cavity. A plenum chamber has been added on the left side of the original cavity so that it can be pressurized, with air escaping through the tube anode for cooling. The bidirectional coupler in the RF drive coaxial line is to the left of the plenum. The RF output coaxial connector is at the lower right hand corner of the TUT cavity.

FIGURE 4.



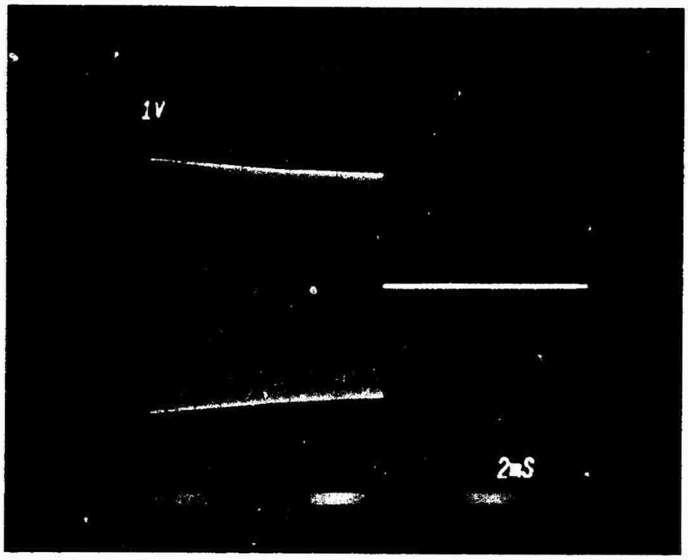
Back view of the rack containing the TUT. At the top is the Tektronix 1000:1 voltage divider to measure the pulsed screen voltage to the TUT. At the center are the three current transformers to measure TUT plate, screen and grid currents. At the bottom is the plate supply crowbar.

FIGURE 5.



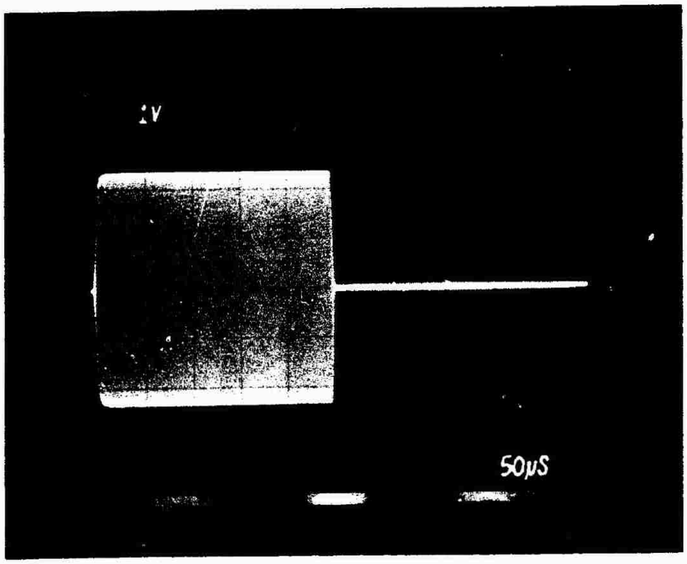
Pulsed RF drive signal to TUT. The operating conditions for the TUT with an X2179F installed were: Eb = 5.5KV, po = 10.233kw, pd = 966w, 10 ms pulse length, 3 pps, 0.03 duty. The drive signal is displayed on a Tektronix 7904 scope. The drive signal amplitude is down by 11 percent at the end of the pulse as compared to the start of the pulse.

FIGURE 6.



Pulsed RF output signal of the TUT with an X2179F installed as displayed by a Tektronix 7904 scope. The TUT operating conditions were: Eb = 5.5KV, po = 10.233 kw, pd - 966w, 10 ms pulse length, 3 pps, 0.03 duty. The RF output signal is down by 11.5 percent at the end of the pulse as compared to the start of the pulse.

FIGURE 7.



Pulsed RF output signal of the TUT with an X2179F installed as displayed by a Tektronix 7904 scope. The TUT operating conditions were: Eb = 5.5KV, po = 10.17 kw, pd = 866 kw, 250 microsecond pulse length, 240 pps, 0.06 duty.

FIGURE 8.